MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APOLLO

GUIDANCE, NAVIGATION AND CONTROL

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USERS' GUIDE TO APOLLO GN&CS MAJOR MODES AND ROUTINES

(REV. 4)
COLOSSUS 3 AND LUMINARY 1E

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This document has been approved by NASA/MSC for use with the Colossus 3 and Luminary 1E GN&CS Programs.

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FOREWORD

This document is an attempt to present, in one volume, a comprehensive, user-oriented description of the APOLLO GN&C system. The objective is to comprise all major modes, routines, and extended verbs defined by the Guidance System Operations Plan (GSOP) and to describe their operation, theory, and interrelationships in sufficient detail for a crew member or mission controller to gain the prerequisite understanding on which to base a more rigorous study of specific, flight-particular details and procedures.

Essentially, then, the GN&C Users' Guide is designed to be system, rather than mission, oriented in that procedural details vary from mission to mission. As a training text defining basic procedures, the Guide will be revised as necessary to remain current; it should not, however, be construed as reflecting the most recent procedures or system configuration. For specific information regarding a particular mission, refer to the appropriate MSC-approved Guidance System Operations Plan (GSOP), Crew Procedures Document, Mission Techniques Document, and Crew Checklist.

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SECTION 1.0

INTRODUCTION

The purpose of this document is to provide crewmembers and mission controllers with a higher-level description of major modes and routines documented in the current Guidance System Operations Plan (GSOP). To do this has required in some instances, however, a review of hardware components, as, for example, the descriptions of the IMU Gimbal Assembly and command module (CM) optics in the "Alignment" section.

The scope, therefore, comprises APOLLO Guidance Computer (AGC) software, plus limited discussions of system hardware when, in the judgement of the writers, such discussions help illuminate the purpose and operation of the individual software programs.

The Users' Guide is organized along the lines of GSOP Section 4, with sections assigned to prelaunch, boost/ascent, coasting-flight navigation, targeting, powered flight, alignment, entry/descent, and to additional extended verbs and routines not described in the earlier sections. As a rule, each section is divided into three subsections: (1) an introduction, (2) command module computer (CMC) programs, and (3) lunar guidance computer (LGC) programs. Each subsection, in turn, is divided into paragraphs describing the individual programs. In some instances, however (e.g., MINKEY Rendezvous and Lunar Descent and Landing), an entire mission sequence is presented, when the sequence rather than the operation of an individual program is the first interest.

In general, each paragraph gives (1) a summary of the guidance and control theory governing the program's application, (2) a discussion of the operational context, (3) an amplified description of crew procedures, and (4) functional flow diagrams of the computer program and the related routines. Again, the Users' Guide is intended as higher-level documentation, analogous to a pilot's handbook. For a design-level description of the system software, refer to the appropriate sections of the Guidance System Operations Plan.

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SECTION 2.0

PRELAUNCH

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2.1 INTRODUCTION TO PRELAUNCH

A requirement of the Apollo Mission is that the orientation of the Inertial Measurement Unit (IMU) be known at launch, so that PIPA acceleration during boost can be correctly integrated into the onboard state vector. In addition, the IMU should maintain a fixed orientation relative to the launch site. Since the earth is rotating, however, this orientation is continually changing with respect to an inertial coordinate system. The IMU must, therefore, undergo continual torquing before launch. The amount of torquing is determined by using a gyrocompass routine to determine North and using the accelerometers to determine vertical; thus the program can compute an earth-fixed coordinate system. For the CSM, x is aligned along the launch axis, z along the vertical axis, and y completes the triad.

The Lunar Module has no prelaunch alignment requirements.

2.2 CMC PRELAUNCH PROGRAMS

The programs listed below constitute the prelaunch alignment capabilities of the Command Module Computer (CMC).

P01, Initialization
P02, Gyro Compassing
P03, Optical Verification of Gyro Compassing

In addition, P00, the CMC Idling Program, and P06, the CMC Power Down Program, are also included in this subsection for numerical convenience—although these two programs can be used at various times throughout the mission.

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2.2.1 P00, CMC Idling Program

P00 is used to maintain the CMC in a state of readiness for entry into other programs. While P00 is operating, the Coasting Integration Routine maintains the CMC's CSM and LM state vectors extrapolated to current time, unless extrapolation is specifically terminated.

2.2.1.1 Computational Modes

P00 operates in either of two modes: (1) state-vector extrapolation allowed; (2) state-vector extrapolation inhibited. Ordinarily, the crew selects P00 by keying VERB 37 ENTR 00 ENTR, and state-vector extrapolation occurs as described under "Computation Sequence," paragraph 2.2.1.2. Keying VERB 96 ENTR, however, terminates extrapolation, and P00 is maintained in an idle state awaiting further crew action.

2.2.1.2 Computation Sequence

In the extrapolation mode, P00 computation is as follows: (1) every 10 minutes, the need for extrapolation is tested; (2) if the current time minus the state-vector time equals at least four time steps (Δt), the CSM state vector is extrapolated, by precision integration, to approximately the present; (3) except when SURFFLAG is set (VERB 44 ENTR), the LM state vector is extrapolated to synchronize with that of the CSM. This synchronizing step is accomplished each time the need for extrapolation is tested—whether the CSM state vector is extrapolated or not. [The value of Δt is a function of the magnitude of the conic position vector ($\underline{r}_{con}$) and the gravitational constant of the primary body (μ_P).] Extrapolation is never to a time in advance of the present; therefore, "approximately the present" means the present minus some fraction of a maximum time step:

$$\Delta t_{max} = \text{minimum}\left(\frac{0.3\, \left|\underline{r}_{con}\right|^{3/2}}{\sqrt{\mu_P}},\ 4000 \text{ sec} \right)$$

In the extrapolation-inhibited mode (initiated by VERB 96 ENTR), the computational sequence is as follows (refer to Figure 2.2.1-1):

1. VERB 96 sets QUITFLAG, causing extrapolation to cease at the end of the current time step (Δt).
2. P00 idles until crew reselects VERB 37 ENTR xx ENTR.

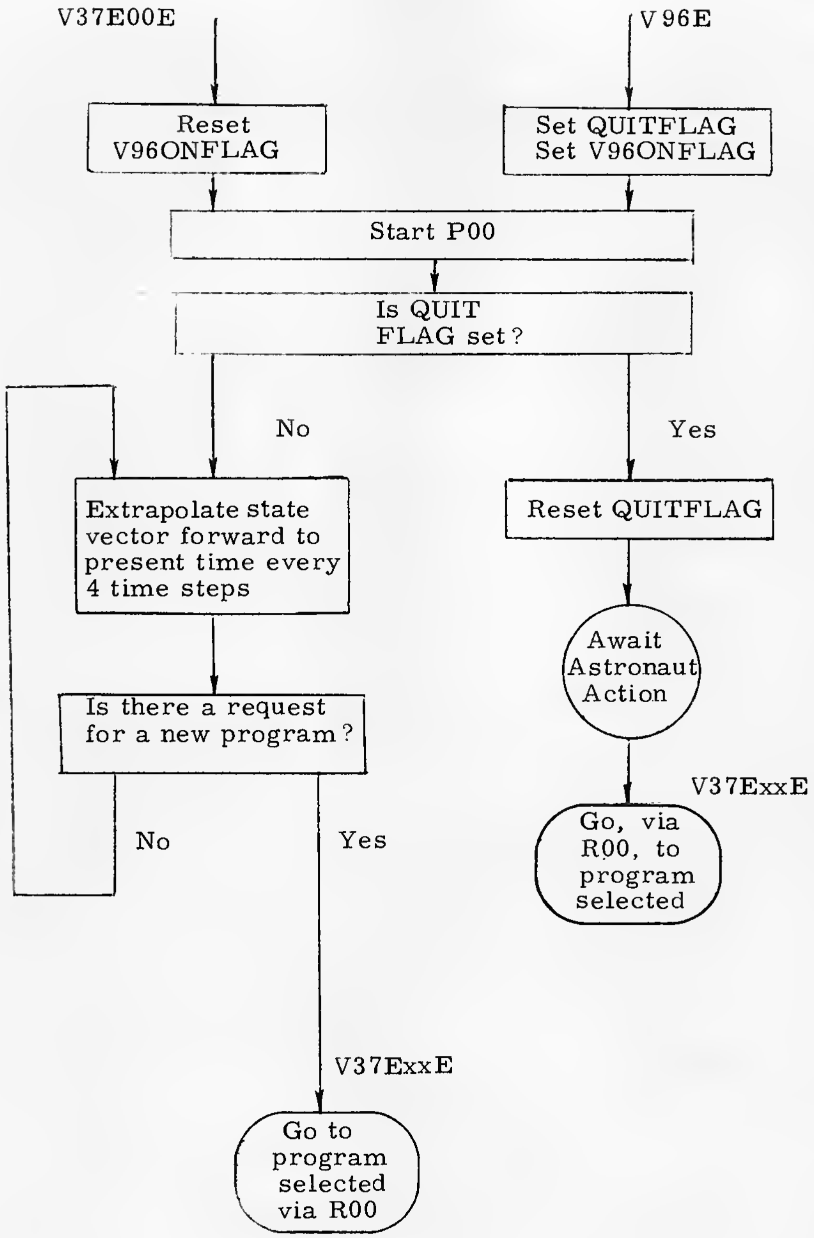


Fig. 2.2.1-1. CMC Idling Program (CSM P00)

2.2.1.3 Procedures

P00 is entered manually by the crew's keying VERB 37 ENTR 00 ENTR. VERB 96 ENTR stops extrapolation, enters P00 automatically, and allows extrapolation to resume upon the crew's reselecting VERB 37 ENTR 00 ENTR. The only displays are 00 in the PROG lights and such other displays as presented when the crew calls up a routine or an extended verb. P00 exits by the crew's selecting a new program (VERB 37 ENTR xx ENTR).

2.2.1.4 Program Coordination

As an idling program, P00 can be selected whenever there are no functional requirements for the GNCS other than maintaining a current state vector for the two vehicles. Attitude maneuvers can be performed either manually or automatically by the RCS digital autopilot (RCS DAP). (See GSOP Section 3.) Gimbal-lock must be avoided during manual attitude maneuver, however, by the crew's monitoring the FDAI ball or by keying VERB 16 NOUN 20 ENTR and monitoring the CDU angles. Gimbal angles for GNC-controlled attitude maneuvers are calculated either by the Crew-defined Maneuver Routine (R62) or by the Rendezvous Final-attitude Routine (R63).

2.2.1.4.1 Crew-defined Maneuver Routine (R62).—This routine can only be entered during P00. The routine allows the crew to specify a GNC-controlled attitude maneuver. DAP rates and deadband limits will be as specified by the crew's prior execution of the Digital Autopilot Data Load Routine (R03).

Routine R62 is entered by the crew's keying VERB 49 ENTR. (See Figure 2.2.1-2.) If the current program is P00 and no other extended verb, marking display, or priority display is active, the DSKY flashes VERB 06 NOUN 22 and displays the final gimbal angles (to the nearest 0.01 deg) for a desired attitude maneuver. (See Table 2.2.1-I.) If P00 is not operating or if another extended verb is active, the DSKY OPR ERR light illuminates to inform the crew that improper conditions exist for entering R62.

Responding to the FL VERB 06 NOUN 22, the crew keys PRO when satisfied with the gimbal angles displayed. To change the gimbal angles, the crew keys VERB 2x ENTR, loads the desired outer-, inner-, and middle-gimbal angles in registers R1, R2, and R3, respectively, and then keys PRO.

After setting a flag specifying the three-axis inertial orientation option for the attitude maneuver, R62 calls the Attitude Maneuver Routine (R60). (See Figure 2.2.1-3.)

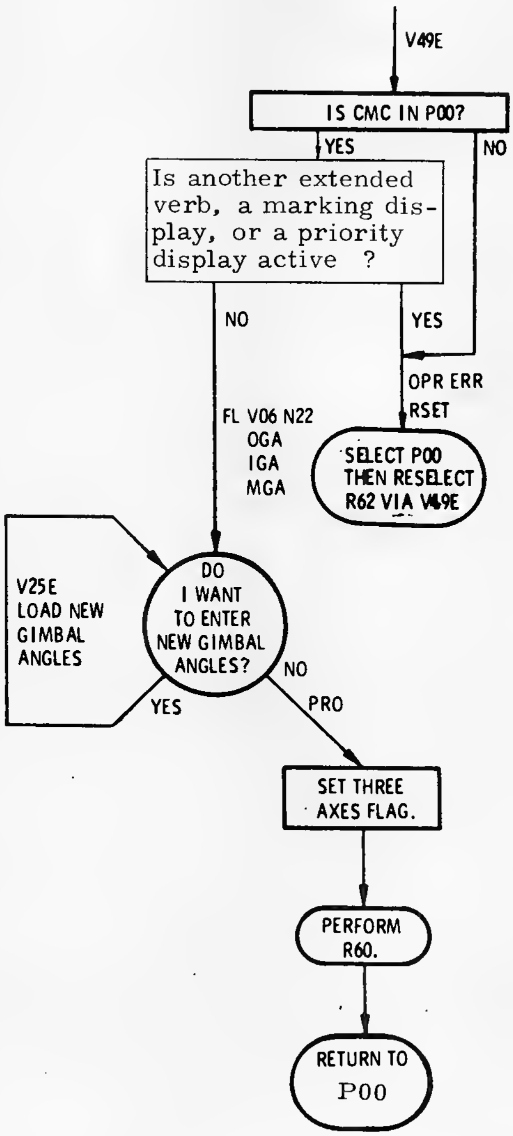


Fig. 2.2.1-2. Crew-defined Maneuver Routine (CSM R62)

TABLE 2.2.1-I

CMC IDLING PROGRAM (CSM P00) DSKY PROCEDURES (SHEET 1 OF 3)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
A	P00 (VERB 37 ENTR 00 ENTR or VERB 96 ENTR)	---	00	Maintain CMC in a state of readiness for entry into other programs.	---	Perform state vector extrapolation if entered by V37 E00E; if entered by V96E, no extrapolation takes place.	During attitude maneuvers, monitor FDAI ball or key in VERB 16 NOUN 20 ENTR to monitor the CDU angles to prevent gimbal lock. Calculation of the gimbal angles is performed either by the Crew-Defined Maneuver Routine (R62) or the Rendezvous Final Attitude Routine (R63). Both of these use the Attitude Maneuver Routine (R60). (See B-1 through B-4 and C-1 through C-5).	Termination of extrapolation is done by keying V96E. Another program cannot be entered during extrapolation. Reinitialize extrapolation by keying V37E00E.
CREW-DEFINED MANEUVER ROUTINE (R62) INTERFACE								
B-1	R62 (VERB 49 ENTR)	FL V06 N22	00	Request crew specify final gimbal angles for a GNC-controlled attitude maneuver.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, call Attitude Maneuver Routine (R60).	PRO, or key VERB 25 ENTR to load new gimbal angles; then PRO.	If CMC not in P00 or another extended verb is active, the OPR ERR light is illuminated.
B-2	R60 (Called by R62)	FL V50 N18	00	Request automatic attitude maneuver to specified final gimbal angles.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform attitude maneuver.	PRO	
B-3	---	V06 N18	00	Nonflashing display of final gimbal angles as maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform maneuver calculation and ICDU drive to achieve final gimbal angles.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to avoid and complete maneuver manually. Observe that the nonflashing V06 N18 returns to FL V50 N18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to FL V50 N18. If MGA reaches ± 75 deg, maneuver terminates and may be completed manually.

TABLE 2.2.1-I

CMC IDLING PROGRAM (CSM P00) DSKY PROCEDURES (SHEET 2 OF 3)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
B-4	---	FL V50 N18	00	Request maneuver to trim attitude within RCS DAP deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO recycle attitude maneuver. Upon crew's ENTR, exit R60/R62.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing V06 N18 display to return until trim maneuver has completed; then FL V50 N18 returns. PRO again repeats the sequence; ENTR terminates R60/R62.
				RENDEZVOUS FINAL ATTITUDE ROUTINE (R63) INTERFACE				
C-1	R63 (VERB 89 ENTR)	FL V06 N78	00	Requests yaw and pitch angles for desired attitude.	R1 xxx.xx Gamma R2 xxx.xx Rho R3 Blank R1 is yaw angle R2 is pitch angle	Upon crew's PRO calculate the final gimbal angles for the desired attitude.	Depress PRO to compute angles; use V24E to change tracking attitude angles then depress PRO.	
C-2	---	FL V06 N18	00	Requests response to computed gimbal angles.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Calculates and stores attitude specification for desired tracking attitude.	Depress PRO to accept angles; use V32E to recycle. Use V34E to exit R63.	
C-3	R60 (Called by R63)	FL V50 N18	00	Request automatic attitude maneuver to specified final gimbal angles.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform attitude maneuver.	PRO	
C-4	---	V06 N18	00	Nonflashing display of final gimbal angles.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform maneuver calculation and ICDU drive to achieve final gimbal angles.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to avoid and complete maneuver manually. Observe that the nonflashing V06 N18 returns to FL V50 N18 when maneuver finishes.	Maneuver rate will be prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to FL V50 N18. If MGA reaches ± 75 deg, maneuver terminates and may be completed manually.

TABLE 2.2.1-I

CMC IDLING PROGRAM (CSM P00) DSKY PROCEDURES (SHEET 3 OF 3)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
C-5	---	FL V50 N18	00	Request maneuver to trim attitude within RCS DAP deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, exit R60/R63.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing V06 N18 display to return until trim maneuver has completed; then FL V50 N18 returns. PRO again repeats the sequence, ENTR terminates R60/R63.

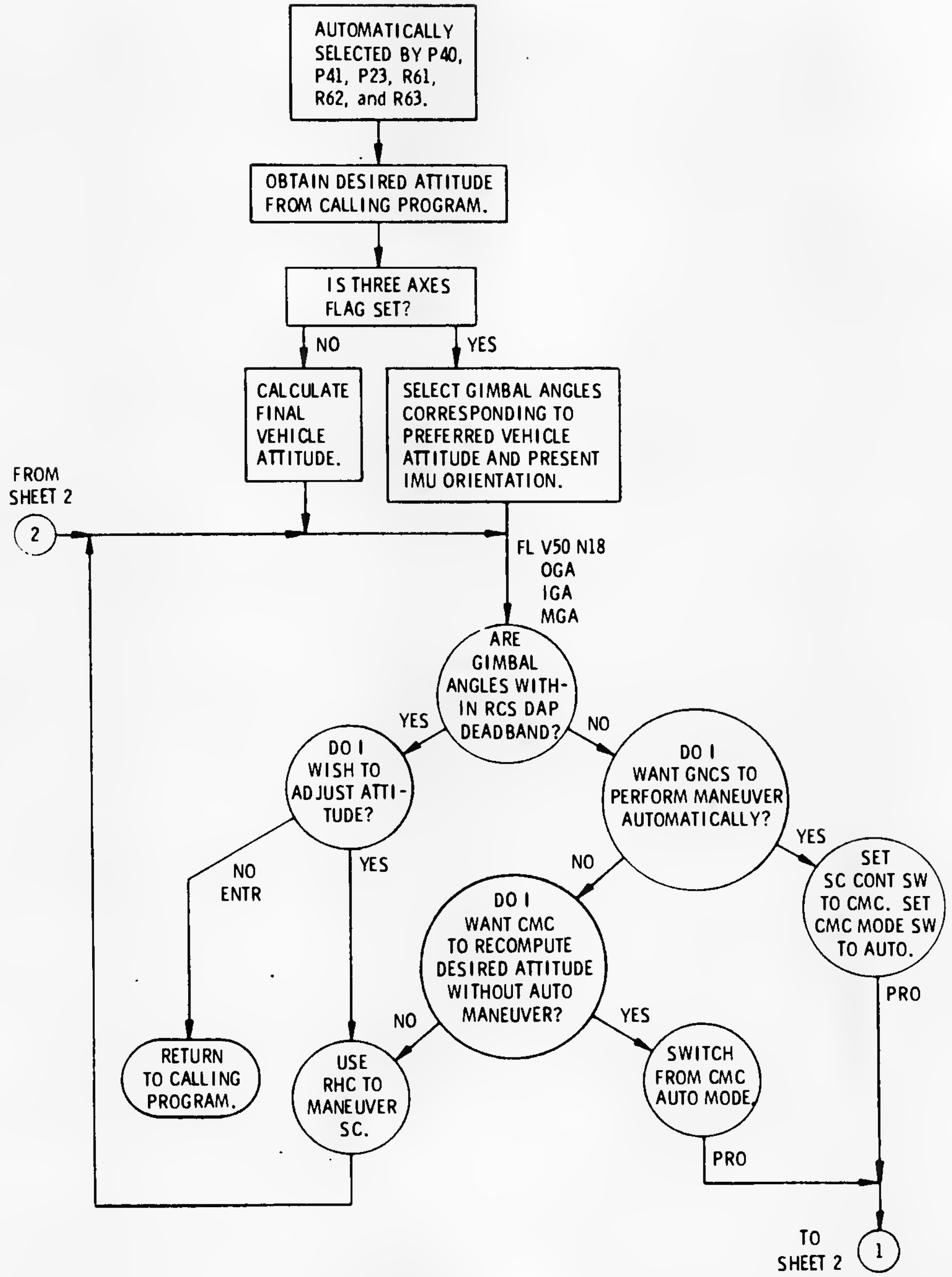


Fig. 2.2.1-3. Attitude-maneuver Routine (CSM R60) (Sheet 1 of 2)

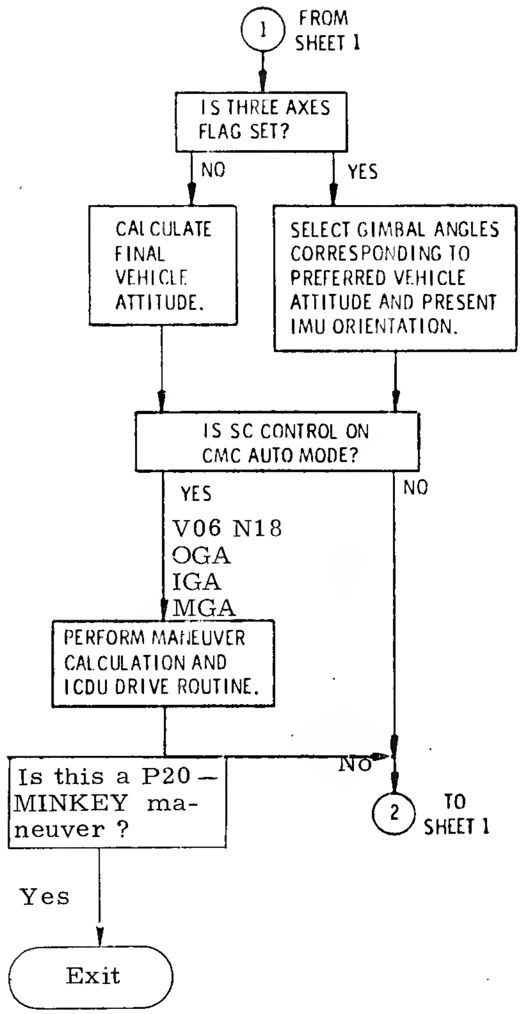


Fig. 2.2.1-3. Attitude-maneuver Routine (CSM R60) (Sheet 2 of 2)

Routine R60 immediately flashes a request to perform an automatic maneuver (FL VERB 50 NOUN 18) to the displayed gimbal angles. To have the maneuver performed automatically, the crew places the SC CONT switch in the CMC position, the CMC MODE switch in AUTO, and keys PRO. The DSKY changes from a FL VERB 50 NOUN 18 display to a non-flashing VERB 06 NOUN 18 display (see Table 2.2.1-I) and performs an automatic maneuver to the desired orientation. The maneuver rate will be that selected the last time Routine R03 was performed. To avoid gimbal lock, the crew monitors the FDAI ball and attitude-error needles; if the middle-gimbal angle begins to exceed 70 deg, the crew can take over manually and complete the maneuver with the rotational hand controller (RHC). At the completion of the automatic maneuver—or anytime the RHC is removed from detent—the flashing VERB 50 NOUN 18 display returns: "Please perform automatic maneuver." If the achieved attitude and the displayed gimbal angles agree, within deadband limits, the crew terminates R60 by keying ENTR; R62 also exits, and the program returns to P00. (VERB 34 ENTR also terminates R60 and goes to P00.) If the crew is not satisfied with the achieved attitude, he can either key PRO to recycle the automatic maneuver or perform further adjustments with the RHC.

2.2.1.4.2 Rendezvous Final-attitude Routine (R63).—This routine provides a means of calculating the final gimbal angles for an attitude maneuver to a desired CSM orientation. When the gimbal angles have been calculated, the routine calls the Attitude Maneuver Routine (R60) for a GNC-controlled attitude maneuver. Time can be saved, therefore, by setting the SC CONT switch to CMC before R63 is called. For automatic maneuvers, Routine R03 must be performed before R63 is called; the CMC MODE switch must be placed in AUTO. Routine R63 can only be called from P00.

Keying VERB 89 ENTR, the crew observes an immediate flashing VERB 06 NOUN 78 (Figure 2.2.1-4) unless one of the following error or alarm conditions exists:

1. If the current program is not P00 or if another extended verb, marking display or priority display is active, the DSKY OPR ERR light illuminates.
2. If the IMU is not on and aligned to an orientation known by the CMC, the IMU Status Check Routine (R02) generates a PROG alarm.

Assuming no error or alarm condition, register R1 of the VERB 06 NOUN 78 display will contain gamma equal to zero; register R2 will contain rho equal to zero for the desired tracking axis; register R3 will be blank. If a different spacecraft axis is desired, the crew must key VERB 24 ENTR and load the correct data in registers

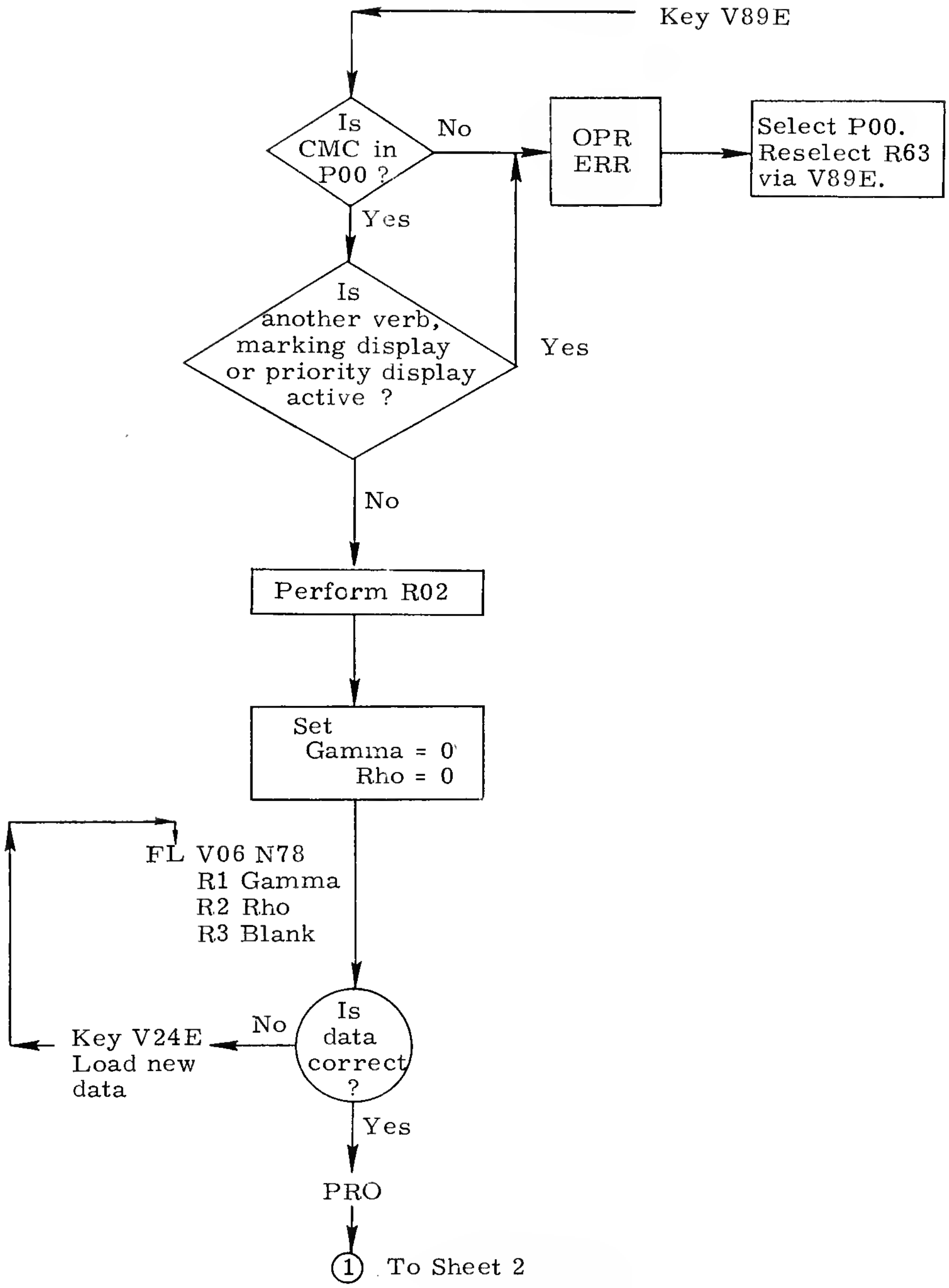


Figure 2.2.1-4. Rendezvous Final-attitude Routine (CSM R63) (Sheet 1 of 2)

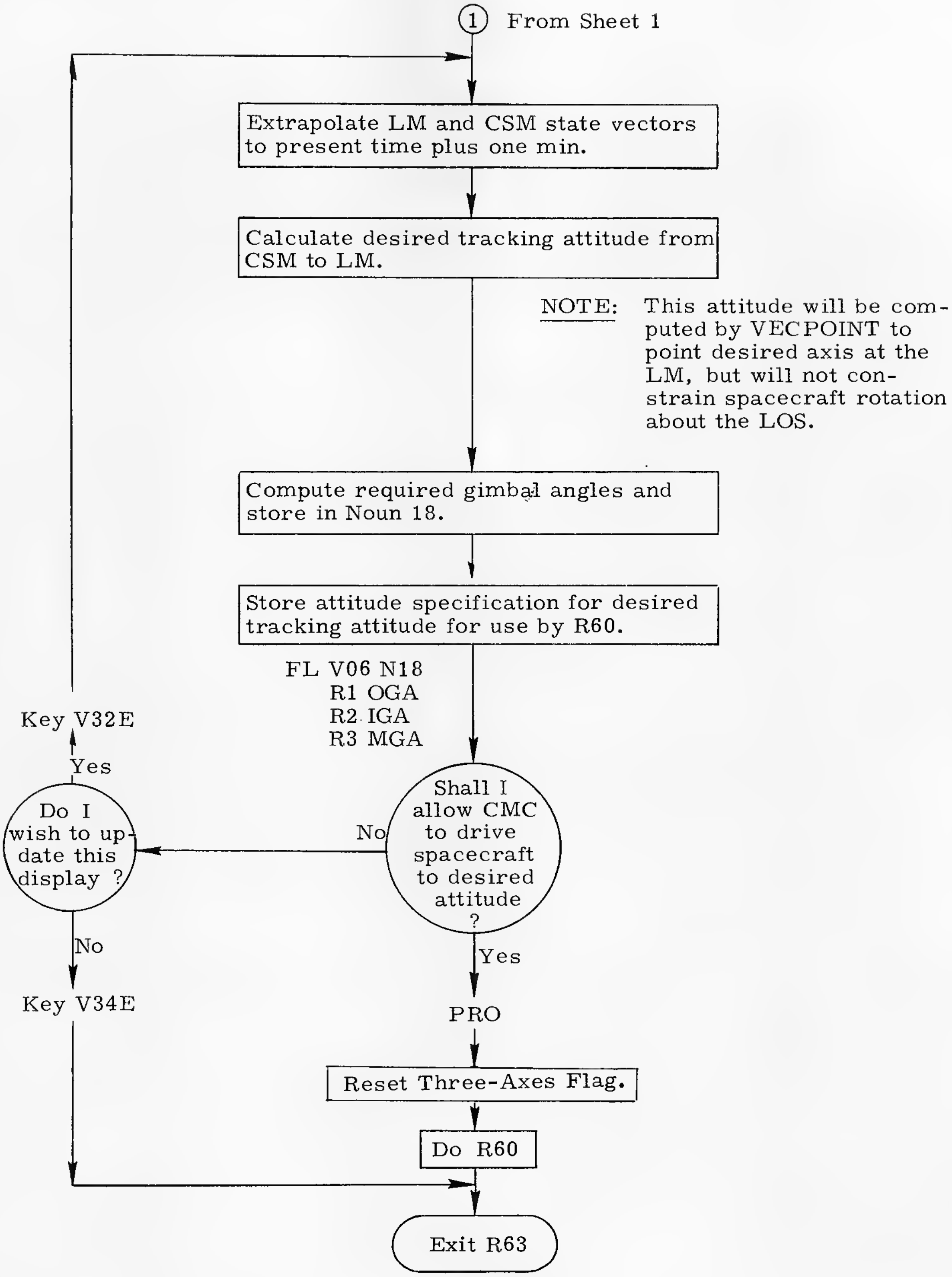


Figure 2.2.1-4. Rendezvous Final-attitude Routine (CSM R63) (Sheet 2 of 2)

R1 and R2. PRO then causes R63 to extrapolate the CSM and LM state vectors to the present +1 minute, calculate the appropriate CSM attitude, and compute the required gimbal angles. The gimbal angles are then displayed by a flashing VERB 06 NOUN 18. (See Table 2.2.1-I.) If the crew is satisfied with the angles displayed and wishes the GNC to control the maneuver, he keys PRO, which causes the Attitude Maneuver Routine (R60) to be called. (Routine R60 is as described in paragraph 2.2.1.4.1.) Otherwise, the crew either can key VERB 32 ENTR to recycle R63 for a later solution or can terminate R63 by keying VERB 34 ENTR, which returns the program to P00. In the nominal condition, the maneuver to point the specified axis at the LM is completed in R60; R63 then returns, only to exit to P00.

2.2.1.4.3 Other P00-limited Extended Verbs.—In addition to R62 and R63, the following extended verbs are only executed during P00:

a. DSKY Light Test (V35)*
b. Load FDAI Error Needles (V43)
c. Display on DSKY the Sum of Each Bank (V91)
d. Coarse-align OCDU (V41N91).

2.2.1.4.3.1 DSKY Light Test (V35).—This verb (Figure 2.2.1-5) provides a means of determining whether all display lights are operational. While in P00, the crew keys VERB 35 ENTR, which causes all display-panel lights to illuminate for 5 sec. VERB 35 then exits. If P00 is not operating, VERB 35 ENTR will cause only the OPR ERR light to illuminate.

> NOTE.—A restart occurring during the performance of V35 can put the IMU into coarse align. After the restart, the crew would observe illumination of the NO ATT light. Recovery procedure is to perform P51.

2.2.1.4.3.2 Load FDAI Error Needles (V43).—This extended verb (Figure 2.2.1-6) was designed primarily for pre-flight groundcheck of the FDAI error needles. The crew can use VERB 43 to load some desired angles into the error needles, and then watch the action of the needles to determine if they are functioning properly. VERB 43 can also be called anytime P00 is operating and neither of the following conditions exists:

---

*Although defined as a regular verb, VERB 35 is included here with the P00-restricted extended verbs.

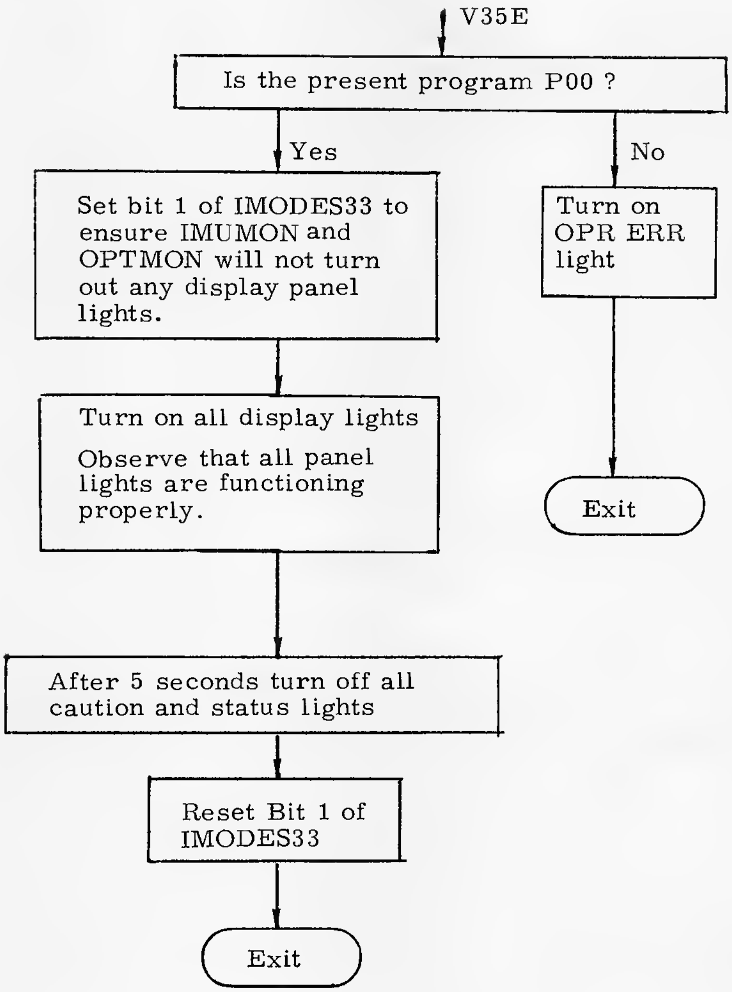


Fig. 2.2.1-5. DSKY Light Test (CSM Regular Verb V35)

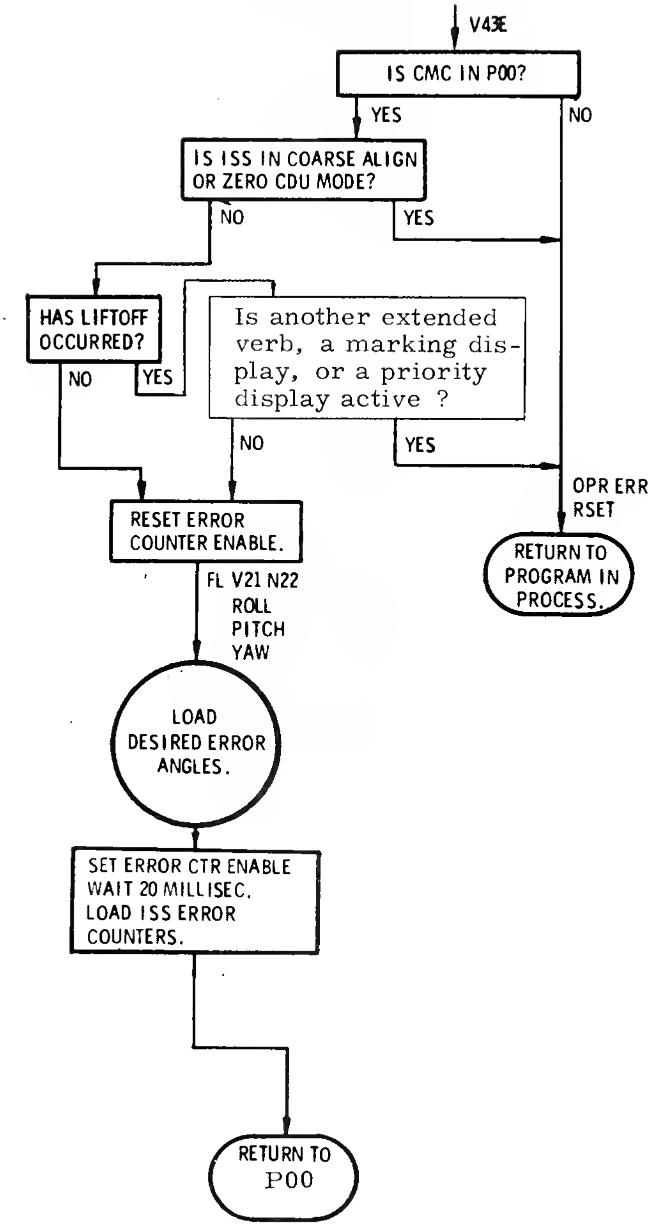


Fig. 2.2.1-6. Load IMU Attitude Error Needles (CSM Extended Verb V43)

a. After liftoff, another extended verb, marking display or priority display is active. (Before liftoff, VERB 43 will override any other extended verb.)

b. The IMU is in the coarse-align or zero ICDU mode.

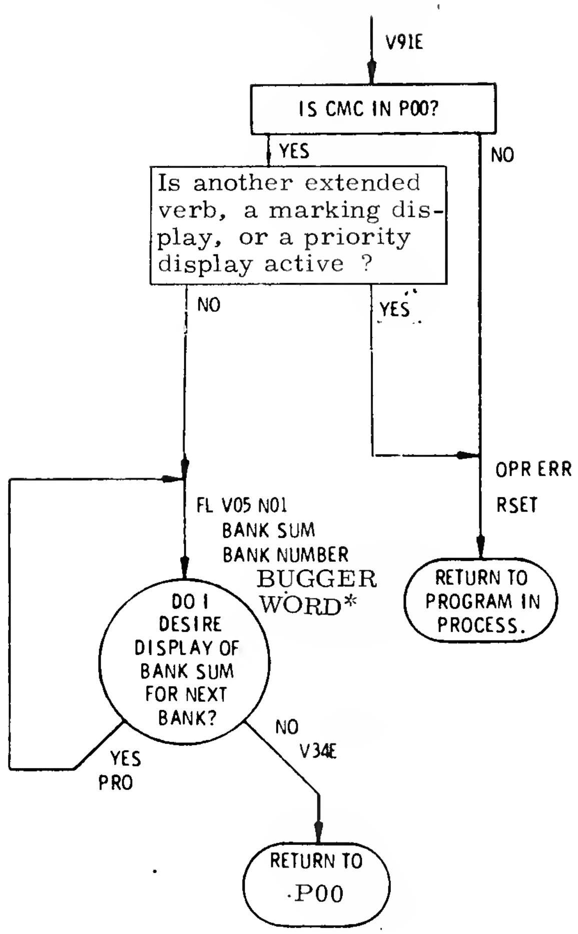
> NOTE.—To use this checkout procedure inflight, the crew must first change the RCS DAP configuration code to zero (no DAP) via R03, and then key in VERB 46 ENTR, which executes the switchover to the no-DAP configuration. If VERB 43 is entered, however, while the DAP is updating the error needles, the crew must re-initialize the DAP via VERB 46 to overcome the resulting bias to the needles.

If P00 is not the active program, or if either condition a or b exists, keying VERB 43 ENTR will cause an OPR ERR light. Otherwise, the DSKY displays a flashing VERB 21 NOUN 22, with registers R1, R2, and R3 corresponding to roll, pitch, and yaw respectively. All three registers will be blank until error angles are entered by the crew. The maximum error angle that can be processed is ±16.88 deg. If a larger value is loaded, the routine will interpret it as 16.88 deg. Also, depending upon the FDAI scale setting, the maximum needle indication in pitch and yaw is 15 deg (roll, 50 deg). Loading the desired error angles in register R1, R2, and R3 (to nearest 0.01 deg), the crew observes a corresponding deflection on the error needles. As soon as the angle data are loaded, the display blanks and VERB 43 exits. The FDAI needles will continue to indicate the loaded angles. To load new angles (zero, for example), the crew must again key VERB 43 ENTR and repeat the loading procedure.

2.2.1.4.3.3 Display on DSKY the Sum of Each Bank (V91).—VERB 91 is a means of fixed-memory checkout. The test can be performed whenever P00 is operating and no other extended verb is active. (See Figure 2.2.1-7.)

Keying VERB 91 ENTR, the crew observes a flashing VERB 05 NOUN 01, with register R1 displaying the sum of the bits contained in the bank whose number is displayed in register R2. Register R3 displays the factor ("bugger word") required to make $|R1| = |R2|$. If $|R1| \neq |R2|$, there is an error in the bank, and use of the CMC should be terminated pending instructions from the ground. To check the next bank, the crew keys PRO, observes that $|R1| = |R2|$, and so on, repeating the procedure until the last bank (43) has been checked. To terminate VERB 91, the crew keys VERB 34 ENTR.

2.2.1.4.3.4 Coarse-align OCDU (V41N91).—VERB 41 NOUN 91 (Figure 2.2.1-8) is used to drive the optics to shaft and trunnion angles specified by the crew. The



*"BUGGER WORD" is a factor required to make $|R1| = |R2|$. If $|R1| \neq |R2|$, there is an error in the bank.

Figure 2.2.1-7. Display on DSKY the Sum of Each Bank (CSM Extended Verb V91)

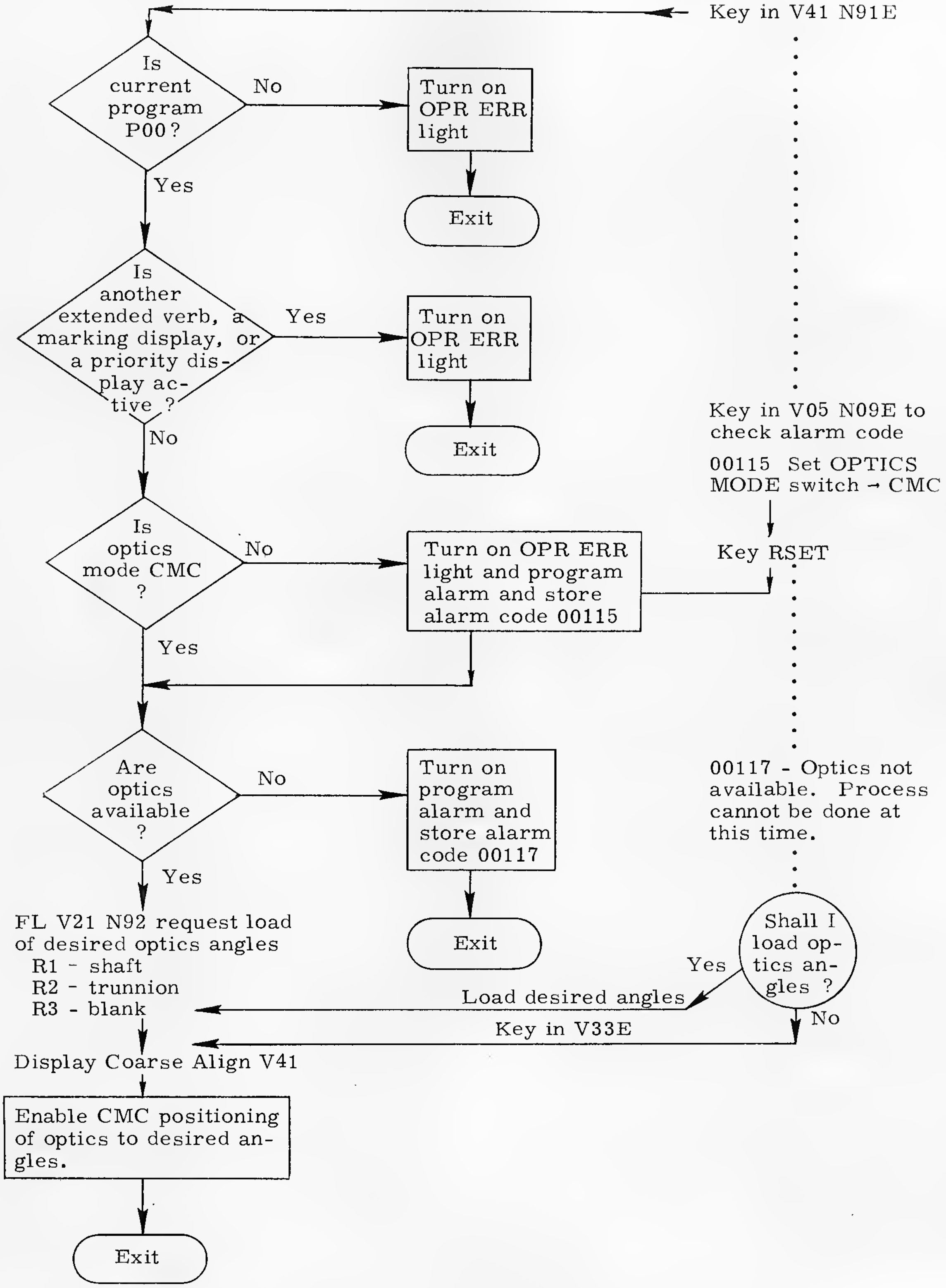


Figure 2.2.1-8. Coarse-align OCDU (CSM Extended Verb V41 N91)

process can be performed only when P00 is operating and no other extended verb, marking display, or priority display is active.

After keying VERB 41 NOUN 91 ENTR, the crew observes a flashing VERB 21 NOUN 92—unless one of the following alarm conditions exists:

a. If the current program is not P00, or if another extended verb, a marking display or a priority display is active, the CMC illuminates the DSKY OPR ERR light and exits.
b. If the optics are not available, the CMC turns on the PROG alarm, stores alarm code 00117, and exits.*

If the OPTICS MODE switch is not in the CMC position, however, the CMC illuminates the OPR ERR light on the DSKY, turns on the PROG alarm and stores alarm code 00115. The crew can key VERB 05 NOUN 09 ENTR to have the alarm displayed, put the OPTICS MODE switch to the CMC position, and key RSET to continue.

If none of the above conditions is present, VERB 21 NOUN 92 flashes requesting load of the desired optics angles. All registers are blank until the crew loads the desired shaft and trunnion angles into registers R1 and R2, respectively. If the crew does not choose to load the optics angles, he keys VERB 33 ENTR and the CMC uses stored angle values. In both cases, the CMC then displays the coarse align VERB 41 for crew observation, enables positioning of the optics to the desired angles and exits.

2.2.1.5 Restrictions and Limitations

If VERB 96 is used to halt integration during Rendezvous Navigation (P20), CSM-LM state-vector synchronization may be lost, and the W-matrix (paragraph 4.2.1) may become invalid and must be reinitialized before resuming navigation.

2.2.1.6 Alarms

Viewing a PROG alarm light on the DSKY, the crew keys VERB 05 NOUN 09 ENTR for a display of the alarm code—unless the code has been displayed automatically. After taking corrective action, the crew keys RSET to extinguish the PROG light and alarm and continues with the program. Alarms most likely encountered in P00 are listed and explained below.

---

*This alarm is not expected since V41 N91 is restricted to P00.

NOTE.—An alarm appears in both R1 and R3 of NOUN 09 if it is the only alarm; in both R2 and R3 if it is the second alarm; and only in R3 if it is the third alarm. R3 always contains the latest alarm. Further, R3 is not cleared by depression of RSET; R1 and R2 are so cleared.

a. Alarm 00115 indicates that the OPTICS MODE switch is not in the CMC position. This alarm may occur during operation of the Coarse-Align OCDU Extended Verb VERB 41 NOUN 91. Correction is to set the OPTICS MODE switch in the CMC position and key RSET to continue.

b. Alarm 00117 indicates that the optics are not available at this time and, therefore, the process of driving the optics to the desired angles cannot be performed. This alarm may occur during operation of Extended Verb V41N91. Since the CMC exits the VERB 41 NOUN 91 process upon storing the alarm code, the crew must choose another time to coarse-align the OCDU angles.*

c. Alarm 01520 is generated if a VERB 37 request is made with the IMU (1) in its 90-sec turn-on period, (2) being caged, and (3) being zeroed.

   It will also be generated if the VERB 37 request is made for a program other than P00 after the entry DAP has been started in P62, during P76 and P77 integration, P06, and during state-vector integration performed in P00 and in P20, options 1, 2, and 5.

   Correction is to wait until the COMP ACTY light is not on continuously—or until IMU moding is complete—and then to reselect via VERB 37, or, if in P06 or in P62/P67, to select P00 and then the desired program.

d. Alarm 00210 indicates IMU not operating when Routine R02 is performed at the beginning of the Rendezvous Final-attitude Routine (R63). Correction is to power up the IMU before selecting R63.

e. Alarm 00220 indicates IMU not aligned to CMC-known orientation (no REFSMMAT) when R02 is performed at the beginning of the Rendezvous Final-attitude Routine (R63). Correction is to perform the IMU-Orientation-Determination Program (P51) before selecting R63.

f. Alarm 20430 indicates a subsurface state vector or, mathematically, computational overflow during state-vector extrapolation. Possible causes are: (1) bad state vector, (2) wrong ephemeris parameters, etc.

2.2.1.7 Restarts

P00 is restart protected.

---

*This alarm is not expected since V41 N91 is restricted to P00.

2.2.2 P01, Initialization—CMC

P01 initializes the platform and provides stable-member orientation for gyrocompassing by P02.

Before starting P01, the crew ensures that the following locations are initialized. These locations are nominally pad loaded.

AZIMUTH	—	azimuth of launch vehicle
LATITUDE	—	latitude of launch vehicle
LAUNCHAZ	—	launch azimuth for IMU
PBIAS	—	PIPA bias compensation — 3 accelerometer compensation terms
PIPASCF	—	PIPA scale factor error compensation — 3 accelerometer compensation scale-factor terms
NBD	—	Gyro bias compensation — 3 gyro bias drift compensation terms
ADIA	—	Gyro input axis compensation — 3 gyro acceleration sensitive input axis drift compensation terms
ADSRA	—	Gyro spin reference axis compensation — 3 gyro acceleration sensitive spin reference axis drift compensation terms

To start P01, the crew keys

VERB 37 ENTR 01 ENTR

The IMU then coarse aligns to the desired orientation

$$[XSM] = \begin{bmatrix} 0 & -1/2(\cos(AZIMUTH)) & 1/2(\sin(AZIMUTH)) \\ 0 & 1/2(\sin(AZIMUTH)) & 1/2(\cos(AZIMUTH)) \\ -1/2 & 0 & 0 \end{bmatrix}$$

When the coarse alignment is completed, CMC enters P02.

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2.2.3 P02, Gyro Compassing—CMC

The purpose of P02 is to provide the proper stable-member orientation for launch. P02 cannot be called via VERB 37. Rather, it is entered automatically when the IMU has been coarse aligned to the desired orientation in P01. Upon entry, P02 performs a leveling routine for 640 seconds; this routine maneuvers the x- and y-inertial components (i.e., gyros and accelerometers) into a plane that is perpendicular to the local vertical. Figure 2.2.3-1 is a diagram of this leveling loop.

After the leveling routine is completed, the gyrocompass routine is started and continues to run until the lift-off discrete (set by the Saturn Instrument Unit) is detected; P11 is then entered automatically. P02 also stops and P11 is selected automatically if the backup lift-off discrete is set by the crew's keying VERB 75 ENTR. The gyrocompass routine provides a known azimuth alignment at liftoff. Figure 2.2.3-2 is a diagram of the gyrocompass loop.

At any time during P02, the crew can change the launch azimuth by keying VERB 78 ENTR, observing the VERB 06 NOUN 29 display of present launch azimuth in R1, and loading the desired launch azimuth via VERB 21. When satisfied with the contents of NOUN 29, the crew keys PRO. Should the launch azimuth be changed during P02, the CMC torques the IMU to the new launch azimuth. The program then re-enters the leveling routine for 320 seconds, and the IMU gyrocompasses to the new launch azimuth.

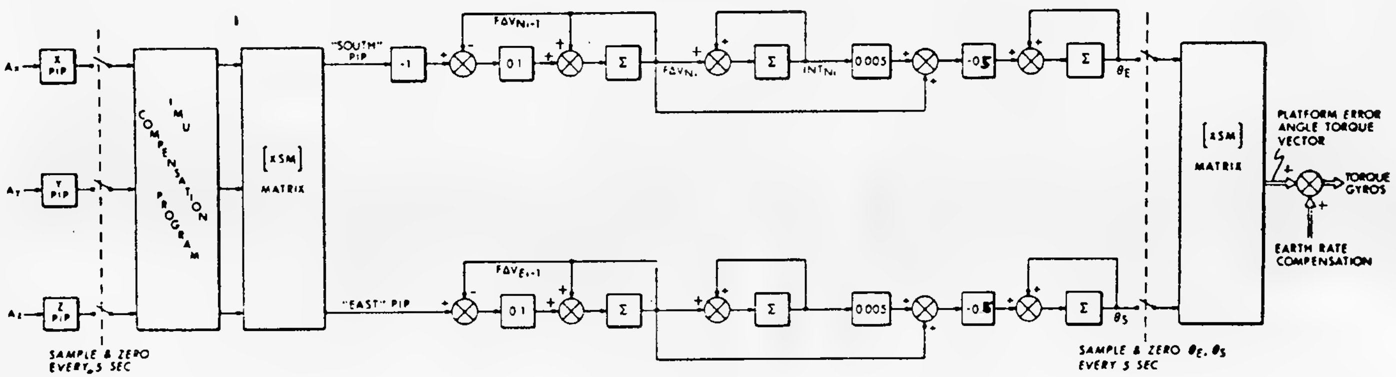

Figure 2. 2. 3-1. Vertical Erection Loop for Prelaunch Alignment

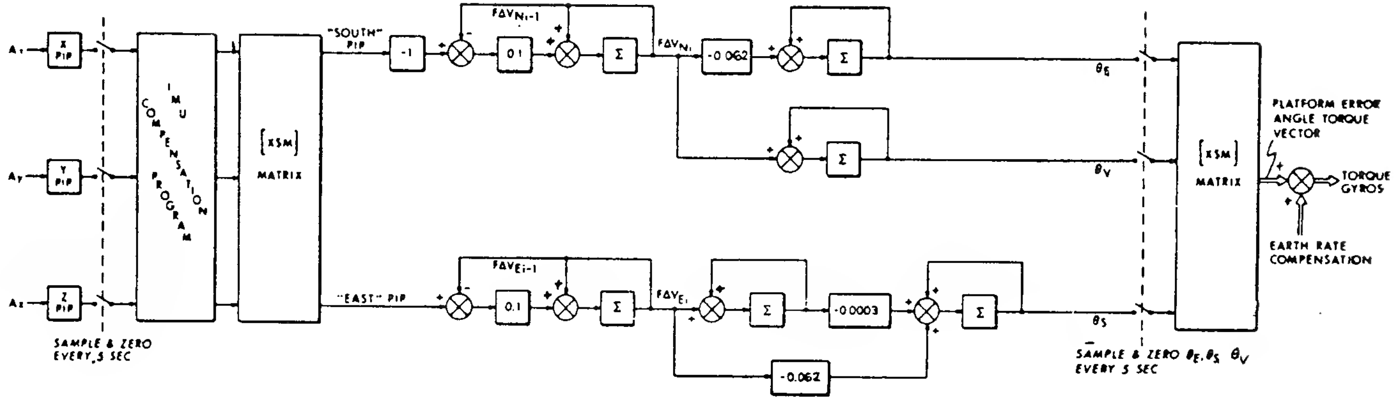

Figure 2. 2. 3-2. Azimuth Alignment Loop for Prelaunch Alignment

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2.2.4 P03, Optical Verification of Gyro Compassing—CMC

P03 provides the crew with an optical check for verification of stable-member alignment during gyrocompassing before launch. The crew verifies alignment by using the Apollo optics to take sightings on two targets whose azimuth and elevation are known. From these two sightings, two line-of-sight vectors are computed and compared to the desired vectors revealing any azimuth error.

Optical verification should not be attempted, however, until the IMU has been continuously gyrocompassing for a minimum of 45 minutes to ensure accurate results. In addition, before starting P03 the OPT ZERO switch must be put in the ZERO position for fifteen seconds, and then returned to the OFF position.

2.2.4.1 P03 Crew Procedures

Ensure that the IMU has been continuously gyrocompassing for at least 45 min. Set the OPT ZERO switch to ZERO for 15 sec, then return switch to OFF position.

1. Key VERB 65 ENTR

Observe the major mode indicator change to 03, and the appearance of azimuth and elevation display of the first target.

<u>FL VERB 06 NOUN 41</u>

R1	xxx.xx deg	Azimuth
R2	xx.xxx deg	Elevation
R3	00001	Target ID

2. VERB 24 ENTR/PRO

   To correct data, key VERB 24 ENTR and load new data.

   When data is satisfactory, key PRO and observe the display of azimuth and elevation of the second target.

<u>FL VERB 06 NOUN 41</u>

R1	xxx.xx deg	Azimuth
R2	xx.xxx deg	Elevation
R3	00002	Target ID

3. VERB 24 ENTR/PRO

To correct data, key VERB 24 ENTR and load new data.

When data is satisfactory, place OPT MODE switch in CMC position, key PRO, and observe the display of marking request.

> NOTE.—The azimuth and elevation data for each target is converted to a half unit line-of-sight vector in the desired stable member coordinate system $XSM_{DESIRED}$—which then becomes the desired line of sight vector for each target, and is designated as T_1 and T_2. The CMC then computes the shaft and trunnion angles to automatically position the optics to point at target 1 for marking.

FL VERB 51

4. MARK

Place OPT MODE switch in MAN. Depress MARK pushbutton when the target is centered and observe display requesting mark termination.

FL VERB 50 NOUN 25

R1	00016
R2	Blank
R3	Blank

5. MARK REJECT/PRO

To reject mark, depress MARK REJECT; program recycles to FL VERB 51 (with N25, R1 = 00016).

To accept mark, key PRO. Position OPT MODE switch to CMC.

> NOTE.—Upon crew's positioning of OPT MODE switch to CMC, shaft and trunnion angles are computed to automatically position the optics for marking on target 2.

Repeat marking procedure for target 2.

NOTE.—From mark data, CMC computes line-of-sight vectors T_1' and T_2' in the actual stable-member coordinate system. Using T_1, T_2 and T_1', T_2' the rotation required to align the IMU to the desired [XSM] is computed and displayed as gyro-torquing angles.

FL VERB 06 NOUN 93

R1	xx.xxx deg	x
R2	xx.xxx deg	y
R3	xx.xxx deg	z

6. PRO/VERB 34 ENTR

To reduce azimuth error to zero, load R1 and R2 to zero, key PRO. *

To terminate optical verification, key VERB 34 ENTR.

---

* This procedure was designed for testing and is not normally performed by crew.

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2.2.5 P06, CMC Power Down

The primary function of the Power Down Program (Figure 2.2.5-1) is to transfer the CMC from the operate to the standby condition, i.e., the normal condition when the computer is not in use. Maximum average power dissipation of the CMC during the standby condition brings the computer down from 70 watts to 15 watts. P06 was designed to be used mainly during such periods as coasting flight and eat and sleep periods. In practice, however, CMC Power Down—in contrast to LGC Power Down—is not nominally used. (An exception is the emergency power down of the CMC during the APOLLO 13 flight.)

2.2.5.1 Procedures

Program initiation is accomplished with the input to the DSKY of a VERB 37 ENTR 06 ENTR by the astronaut. The program flashes VERB 50 NOUN 25 on the DSKY. The purpose of the flashing verb/noun is a Checklist function, with R1 containing the Checklist code 00062_8, indicating the need for a crew response. The crew responds by keying the CMC to the standby condition using the PRO key. The crew depresses PRO and holds it until the STBY light comes on and the DSKY goes blank. (To transfer the CMC from standby to the operate condition, the crew depresses the PRO pushbutton—and holds it—until the STBY light goes out.)

Once the program has been selected, the CMC will be shut down unless a computer restart is performed (VERB 69 ENTR) before the depression of PRO for the standby condition. After P06 selection, the CMC will not honor a new program request (VERB 37 ENTR xx ENTR), a terminate (VERB 34 ENTR), a VERB 33 ENTR, or an ENTR in response to the CMC standby request.

2.2.5.2 Restrictions and Limitations

Should the CMC be allowed to go below the power level for the standby condition, the CMC would require reinitialization of erasable memory via a VERB 36 ENTR and updating of the inertial state vectors and GET.

The standby period can be permitted to last indefinitely. If the CMC is left in standby more than 23.3 hours, however, the GET must be updated. Also, the power

to the ISS should not normally be permitted to fall below standby power requirements.*
For example, the IMU HEATER circuit breakers must be left on except in extreme emergency. If the IMU heaters are off for extended periods, the IMU calibration is no longer valid.

2.2.5.3 Restarts

During initialization, P06 has restart protection. Should a restart occur at this time, the crew sees the RESTART light illuminate, but the program continues. Should a restart occur after initialization, however, the crew must reselect P06.

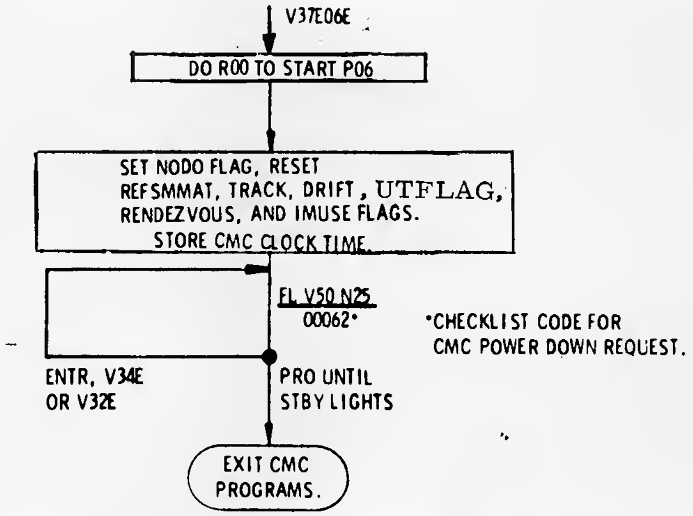

Figure 2.2.5-1. CMC Power Down Program (CSM P06)

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* This condition is particularly critical for the LGC Power Down Program. Refer to paragraph 2.3.2.

2.3 LGC PRELAUNCH PROGRAMS

This subsection contains the following programs:

P00, LGC Idling (paragraph 2.3.1)
P06, LGC Power Down (paragraph 2.3.2)

Unlike the CMC, the LGC has no prelaunch alignment requirements. The programs in this subsection are not restricted to prelaunch, but can be used—in accordance with premission planning—at various times throughout the mission.

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2.3.1 P00, LGC Idling Program

The LGC Idling Program is essentially the same as CMC P00. As in the CMC P00, while SURFFLAG is set, indicating the LM is on the moon, no LM state-vector extrapolation occurs. In the LGC, SURFFLAG is set automatically by P68, the Landing Confirmation Program, rather than manually by the crew. The reader is referred to the description of CMC P00, paragraph 2.2.1, with the understanding that LGC be substituted for CMC. Because the CMC routines and extended verbs included in that description may be different for the LGC, however, the reader should refer directly to the LGC descriptions of those routines and extended verbs.

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2.3.2 P06, LGC Power Down

The primary function of the Power Down Program is to transfer the LGC from the operate to the standby condition, i.e., the normal condition when the computer is not in use. The LGC Power Down Program is essentially the same as CMC P06. Refer, therefore, to the description of CMC P06, paragraph 2.2.5.

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SECTION 3.0

BOOST/ASCENT

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3.1 INTRODUCTION TO BOOST/ASCENT

The programs listed below constitute the boost, ascent, and translunar insertion (TLI) capabilities of the Command Module (CM) and the Lunar Module (LM). These powered-flight programs provide initialization data for the computer and monitoring capabilities for the crew:

- P11, Earth-orbit-insertion Monitor—CMC (paragraph 3.2.1)
- P15, TLI Initiate/Cutoff—CMC (paragraph 3.2.2)
- P12, Nominal Ascent Program—LGC (paragraph 3.3.1)
- P70, Descent Propulsion System Abort—LGC (paragraph 3.3.2)
- P71, Ascent Propulsion System Abort—LGC (paragraph 3.3.3).

The five programs have been grouped together mainly for convenience of outline. Despite some superficial similarities, however, they are essentially different. For example, P11 calculations are based on pad-loaded polynomial coefficients representing the nominal attitude profile for boost to earth orbit. These coefficients are used by the Attitude Error Subroutine discussed in paragraph 3.2.1.2.3. P15 provides a backup means of initiating, monitoring, and terminating TLI.

Calculations for the LGC programs, P12, P70, and P71, however, are based on the relationship between the current state vectors of the CSM and the LM. These calculations are performed and used by the Ascent Guidance to put the LM in an orbit suitable for rendezvous. The Ascent Guidance is the controlling routine for P12, P70, and P71 and is explained in detail in subsection 3.3.

Further, although all five programs provide initialization data, the parameters initialized and the methods used for initialization are different. Refer, therefore, to the appropriate paragraph for a detailed explanation of the initialization functions.

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SUBSECTION 3.2

CMC BOOST PROGRAMS

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3.2.1 P11, Earth-orbit-insertion Monitor—CMC

The primary function of P11 is to monitor the progress of the launch vehicle from liftoff until earth orbit has been achieved. In conjunction with this function, P11 performs the following:

a. Indicates to the astronaut that the CMC has received the liftoff discrete.
b. Zeros the CMC clock and updates the reference ephemeris time.
c. Computes the CMC state vector at liftoff and starts the AVERAGEG cycle, using the computed state vector.
d. Computes REFSMMAT.
e. Monitors attitude errors, altitude, velocity, and rate of altitude change.
f. Provides the means for automatic (CMC) control of the launch vehicle should the Saturn inertial platform fail.

P11 outputs are the liftoff time, the reference ephemeris time of liftoff, REFSMMAT, the DSKY NOUN 62 display, the FDAI needles display of attitude errors, and steering signals to the Saturn instrumentation unit (IU) in case of CMC takeover of the launch vehicle.

Table 3.2.1-I gives the DSKY displays for P11; Table 3.2.1-II lists the extended verbs.

3.2.1.1 P11 Saturn Takeover

During P11, the crew should monitor the L/V RATE and the L/V GUID lights. Illumination of both of these lights, or of the L/V GUID light alone, indicates that the Saturn launch vehicle instrumentation unit has signaled failure of its inertial platform to the spacecraft. The crew must then set the LAUNCH VEHICLE GUIDANCE switch to the CMC position, allowing the CMC to assume automatic control of the launch vehicle. Automatic control can be used—during P11—for all three boost stages of the Saturn V vehicle, S-IC, S-II, and S-IVB. During the S-IC stage, automatic control provides polynomial guidance for the launch vehicle; during the S-II and S-IVB stages, however, automatic control provides only attitude-hold commands.

Should it become necessary, the crew can assume manual control (stick function) of the launch vehicle and issue control signals to the instrumentation unit using the rotational hand controller (RHC). Manual control can also be selected during all three stages of Saturn, S-IC, S-II, and S-IVB. (Although selection of manual control is most likely to occur during the S-II and S-IVB stages, the software does not

TABLE 3.2.1-I

DSKY DISPLAYS ASSOCIATED WITH CSM P11

DSKY	Initiated by	Purpose	Condition	Register
V06N62	P11	Display	Inertial velocity (VI) Rate of altitude change (HDOT) Altitude (H)	R1 xxxxx. fps R2 xxxxx. fps R3 xxxx. x n. mi.
FL V16N44	R30 (V82E)	Display of orbital parameters	Apogee Altitude Perigee Altitude Time of free fall	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min,sec
FL V16 N32	Astronaut (R30) Key N32E	Display time from perigee in R30		R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec
FL V16 N50	Astronaut (R30) Key N50E	Display splash error in R30	Δr miss distance Perigee Time of free fall	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min,sec

TABLE 3.2.1-II

EXTENDED. VERBS USED WITH CSM P11

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters	See paragraph 3.2.1.4
75 ENTR	Enter P11	To manually initiate P11	This is the backup case and is essentially a part of P02.

preclude its selection during the S-IC stage.) To facilitate the speed of manual takeover, register R1 of NOUN 46 should be preloaded with a DAP configuration code of 3, via R03. This procedure is usually performed before liftoff. To begin manual takeover, then, the crew (1) ensures that the LAUNCH VEHICLE GUIDANCE switch is in the CMC position (2) keys VERB 46 ENTR into the DSKY to activate the DAP, and (3) provides control signals to the launch vehicle using the RHC.

Entry of VERB 46 during the S-IC stage terminates polynomial guidance and allows the crew RHC commands to control Saturn flight. Similarly, entry of VERB 46 during the S-II and S-IVB stages terminates the Attitude Error Subroutine and leaves only crew-initiated RHC commands for launch vehicle control.

3.2.1.2 Computational Sequence

P11 is usually automatically selected by P02 (the Gyro Compassing Program) when the CMC receives the liftoff discrete. If P11 has not been automatically entered at liftoff, the crew can key VERB 75 ENTR to start P11.*

P11 consists of four major subroutines: Time, State, Attitude Error, and Display. The Time subroutine, or beginning of P11, is selected by P02 within 0.5 sec of receipt of the liftoff discrete. The State subroutine is executed immediately after Time and is through within 1 sec of receipt of the liftoff discrete. The cycling of the Attitude Error subroutine is then started, updating the attitude error display on the FDAI needles approximately every 0.5 sec until P11 exits. (The pitch polynomial calculation defines pitchover of the spacecraft longitudinal axis from the pad local vertical at liftoff.) After the completion of the pitch program until P11 exits, the desired gimbal angles are maintained constant. As the Attitude Error subroutine is started, the Display subroutine is being executed every 2 seconds following the AVERAGEG computation. The Attitude Error subroutine is not synchronous with the Display subroutine.

3.2.1.2.1 Time Subroutine.—The Time subroutine reads the actual liftoff time, zeros the CMC clock at liftoff, updates the reference ephemeris time, and sets up the other subroutines. The Time subroutine of P11 is entered within 0.5 sec of the receipt of the liftoff discrete. The clock zeroing and the reference ephemeris time are not changed for the remainder of the mission unless updated by P27.

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*VERB 75 ENTR is a backup procedure used in case the hardware does not set the proper bit when the umbilical cord is removed.

3.2.1.2.2 State Subroutine.—The State subroutine computes the CMC state vector (in reference coordinates) at liftoff and starts the AVERAGEG calculations using the computed state vector. It also computes the REFSMMAT matrix, which relates the IMU stable member orientation to the Reference Coordinate System. The State subroutine has no immediately visible output; it completes its computations within 1 second of the receipt of the liftoff discrete.*

3.2.1.2.3 Attitude Error Subroutine.—The Attitude Error subroutine computes and transmits to the FDAI needles the difference between a computed nominal Saturn launch vehicle attitude profile and the actual attitude profile, as measured by the CM IMU. The subroutine is cycled approximately every 0.5 second. After the CMC pitch polynomial calculation exits, the desired gimbal angles are maintained constant. This subroutine operates in two modes:

1. Display mode—attitude error needles only.
2. Saturn takeover mode—DC output voltage from ICDUs sent to the Saturn instrumentation unit to command attitude of entire vehicle during automatic takeover.

NOTE.—In this mode, the FDAI attitude error needles display contains a constant bias computed at takeover.

3.2.1.2.4 Display Subroutine.—Using the results of each AVERAGEG cycle, the Display subroutine computes the Saturn launch vehicle inertial velocity (VI), the rate of change of altitude (H-dot or HDOT), and the altitude (H) above the launch-pad radius. The subroutine updates the display of these quantities (VERB 06 NOUN 62) every 2 seconds following the AVERAGEG cycle.

3.2.1.3 P11 Procedures

Figure 3.2.1-1 is a flowchart of P11. Figure 3.2.1-2 is a typical timeline of crew activity from launch to earth orbit. Since P11 is automatically selected by P02, the crew must first monitor the DSKY for display of major mode 11. The recommended procedure for the backup mode is that the crew key VERB 75 into the DSKY during P02. Then, after liftoff, if P11 does not begin automatically—11 is not displayed—the crew need only key ENTR to initiate P11.

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* The output of the State subroutine is used as input for computing other things and never appears to the crew as such.

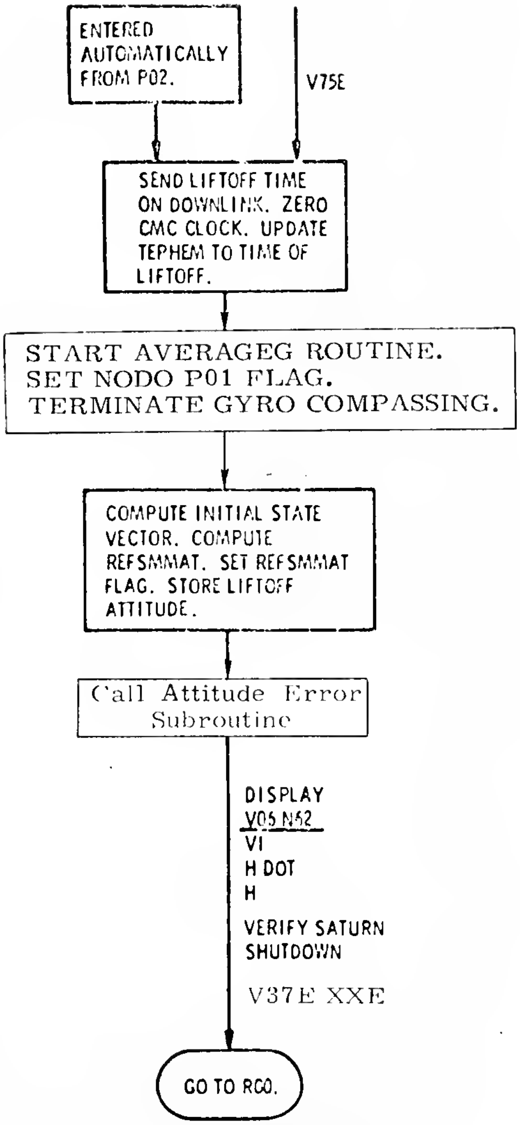

Figure 3.2.1-1. Earth-orbit-insertion Monitor Program (CSM P11)

Program Time	Event	VERB-NOUN Display	DSKY Registers	Crew	CMC Takeover of Saturn	FDAI Att. Err. Needle Display
-03:00	Backup V75	PROG 02	R1 R2 R3	Key V75 (No ENTR)		
-00:09	Ignition	PROG 02 VERB 75	R1 BBBBB R2 BBBBB R3 BBBBB			
+00:00	Liftoff light on					
+00:01	P11 Auto Start	PROG 11 VERB 06 NOUN 62 VI, HDOT, HPAD	R1 XXXXX.ft/sec R2 XXXXX.ft/sec R3 XXXX. X n. mi.	If no P11, key ENTR		
+00:10	Clear launch tower			Monitor FDAI Attitude Error Needles monitor L/V GUID and L/V RATE light. If on, set LAUNCH VEHICLE GUIDANCE sw to CMC. Change to manual mode, if necessary, to continue S-IC, S-II, or S-IVB stages.	Polynomial guidance Automatic or manual mode allowed	Pitch, Roll, Yaw
+00:11	Start of Pitch and Roll Program					
+00:30	Roll Program Complete					
+00:42	Abort Mode IB					
+01:56	Abort Mode IC		R3 0016. 5 n. mi.			
+02:39	CMC Pitch Poly-nomial complete					
+02:43	S-IC/S-II staging				Auto mode - Attitude hold	Roll, Yaw (Pitch needle saturates) CMC maintains desired attitude constant
+02:44	S-II ignition					
+03:18	L. E. T. Jet - Abort Mode II					
+09:00	Abort Mode IV (2 burn)		R1 ≥ 22200 ft/sec R2 ~ 160 ft/sec R3 ~ 100 n. mi.			
+09:11	S-II off					
+09:14	S-II/S-IV B staging					
+09:17	S-IVB ignition					
+10:16	Abort Mode IV (1 burn)		R1 ≥ 23400 ft/sec			
+11:39	Insertion Display orbital parameters Select P00	VERB 16 NOUN 44 HA, HP, TFF	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min, sec	Key: V82 ENTR PRO V37 ENTR 00 ENTR		

Figure 3. 2. 1-2. Typical Timeline of Crew Activity from Launch to Earth Orbit

As the Attitude Error subroutine begins, the crew can monitor the FDAI attitude error needles' indication of launch vehicle attitude error. During a nominal launch and after separation of the launch escape tower, the crew will note the gradual saturation of the pitch needle. The yaw and roll needles should remain close to zero at all times. After the CMC pitch polynomial calculations exit, the desired attitude will be held constant until a new program is selected.

The DSKY will display VERB 06 NOUN 62, updating the display every 2 seconds after the AVERAGEG cycle, through the three boost stages until P00 is selected following S-IVB shutdown. The crew monitors the VERB 06 NOUN 62 display by comparing the displayed values with the Launch Phase Cue Card values.

P11 is exited by keying VERB 37 ENTR xx ENTR to select a new major mode. AVERAGEG cycling will continue until a new major mode has been selected.

3.2.1.4 Auxiliary Routine

The crew can call the Orbital-parameters Display Routine (R30) during P11 by keying in VERB 82 ENTR. (Refer to paragraph 9.2.3 for a description of R30.) R30 computes apogee altitude, perigee altitude, and time of free fall and displays these values via VERB 16 NOUN 44. If perigee altitude is greater than 300,000 ft, R30 sets time of free fall to minus 59 min 59 sec and computes time from perigee. A display of time from perigee can be called by keying NOUN 32 ENTR. SPLERROR, an approximate indication of landing point miss distance, can be called by keying NOUN 50 ENTR.

The computations made during this routine are updated about every 2 seconds if the AVERAGEG routine is on when R30 is called. The crew must key PRO to return to the NOUN 62 display of P11.

3.2.1.5 Alarms

There are no program alarms associated with P11.

3.2.1.6 Restarts

P11 is restart protected.

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3.2.2 P15, TLI Initiate/Cutoff—CMC

The TLI Initiate/Cutoff Program (P15) is a CMC program enabling the astronaut to monitor, and provide backup control for, the translunar insertion (TLI) maneuver performed by the SATURN SIVB engine. Normally, the function of P15 is exclusively to monitor the initiation and performance of the TLI maneuver, beginning with the start of TB6 sequencing and ending with SIVB cutoff. In the event of SATURN instrumentation-unit (IU) failure, however, P15 provides a backup capability for initiating TB6 sequencing, SIVB ignition, and SIVB cutoff. Also, for use in conjunction with the CMC's SATURN steering takeover function (Manual, or Stick, Mode—described in GSOP Section 3), P15 allows the crew to call up a display (NOUN 62) of the current inertial velocity, altitude rate, and altitude—completing the loop enabling the crew to function as an alternate source of steering signals to the SATURN IU autopilot.

3.2.2.1 Summary

Before the SATURN IU can receive signals issued by the CMC, two conditions must exist: (1) the LV GUID switch must be in the CMC position; (2) the SATURN IU must have described itself as failed. Normally, the LV GUID switch is in the IU position and is only moved to CMC upon positive indication of IU failure.

Preliminary procedures include the crew's performing the DAP Data Load Routine (R03) and loading Data Code 3 (SIVB) into position A of NOUN 46 Register 1. The FDAI should be configured for ORDEAL, with an appropriate altitude and body selected for an orbital-rate pitch profile analogous to the burn-attitude profile. Then, with the FDAI Ball slewed to 0-deg pitch when the spacecraft is at the initial burn attitude, a continuous visual reference becomes available in the event of manual takeover.

At the specified time, the crew keys VERB 37 ENTR 15 ENTR, and P15 begins to perform calculations, issue discretes, and provide DSKY displays as shown on the P15 functional flowchart (Figure 3.2.2-1). These discretes are not allowed to reach the IU, however, unless both conditions described at the beginning of paragraph 3.2.2.1 exist, i.e., the LV GUID switch in CMC, and the SATURN IU self-described as failed. Should the astronaut observe positive indication of IU failure during TB6 (see procedures below), he would move the LV GUID switch from IU to CMC, and the appropriate P15 discretes would then be transmitted to the IU. During the insertion burn, the crew would monitor the altitude rate (displayed in NOUN 62) and make RHC pitch corrections referencing the FDAI ball.

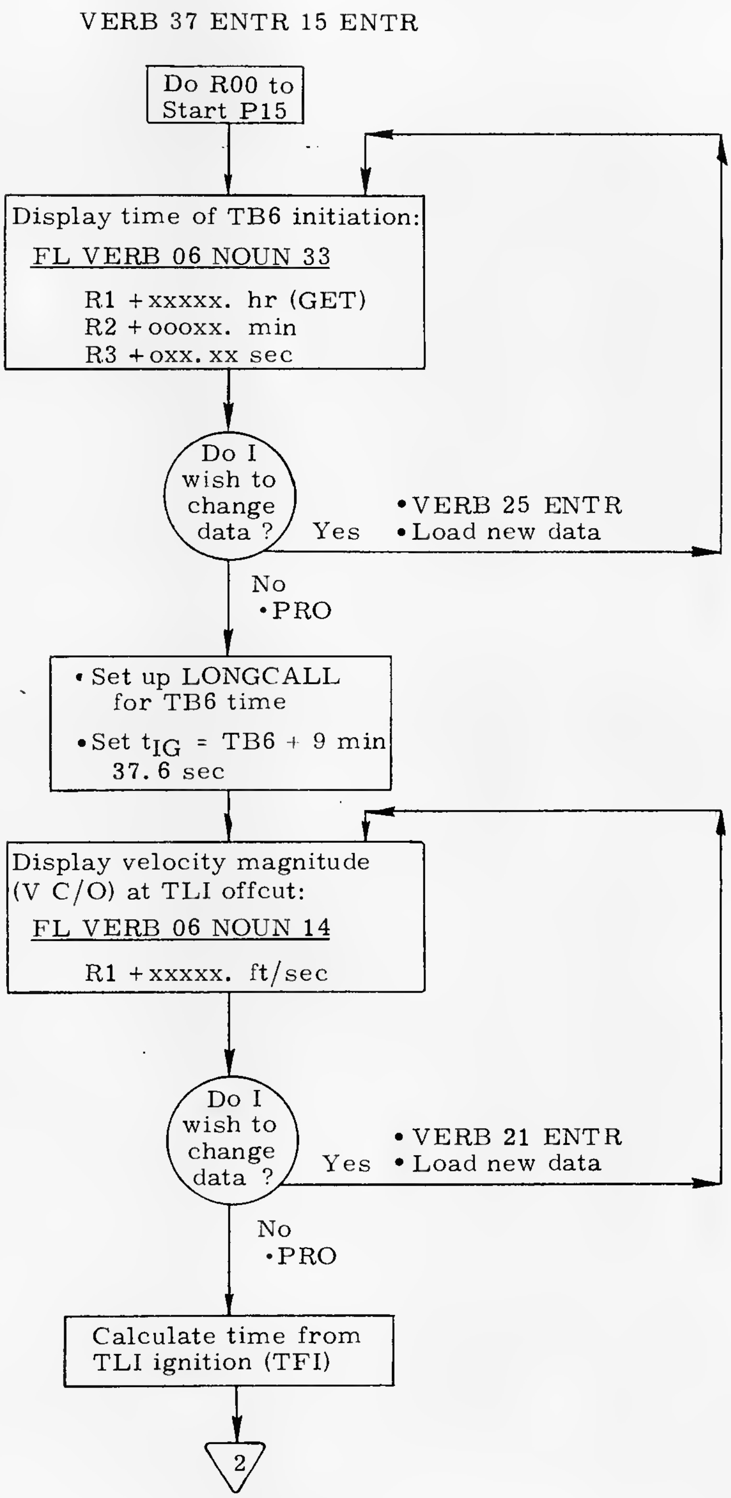

Figure 3. 2. 2-1. TLI Initiate/Cutoff Program
(CSM P15) (Sheet 1 of 3)

2

- Display TFI (Maximum reading, 59B59; "-" before nominal ignition; "+" after nominal ignition).
- Display velocity to be gained (v_G) at TLI, i.e., v_G = V C/O - VI
- Display magnitude of permanent state vector velocity (VI)
- Update display every second

  VERB 06 NOUN 95

  R1 ± xxBxx min-sec TFI
  R2 ± xxxxx. ft/sec v_G
  R3 + xxxxx. ft/sec VI

- Wait until TB6
- At TB6, set SIVB injection-sequence-start bit (Bit 13 of Channel 12), and
- Turn on UPLINK ACTY light

- Wait until TB6 +10 sec
- At TB6 +10 sec, reset SIVB injection-sequence-start bit
- Turn off UPLINK ACTY light

- Set $t_{DEC} = t_{IG}$ - 100 sec
- Perform State-vector Integration (MIDTOAVE) Routine (R41)
- Wait until t_{IG} - 105 sec

- At t_{IG} -105 sec, blank DSKY verb, noun and data registers for 5 seconds.
- Wait until t_{IG} -100 sec

3

Figure 3.2.2-1. TLI Initiate/Cutoff Program (CSM P15) (Sheet 2 of 3)

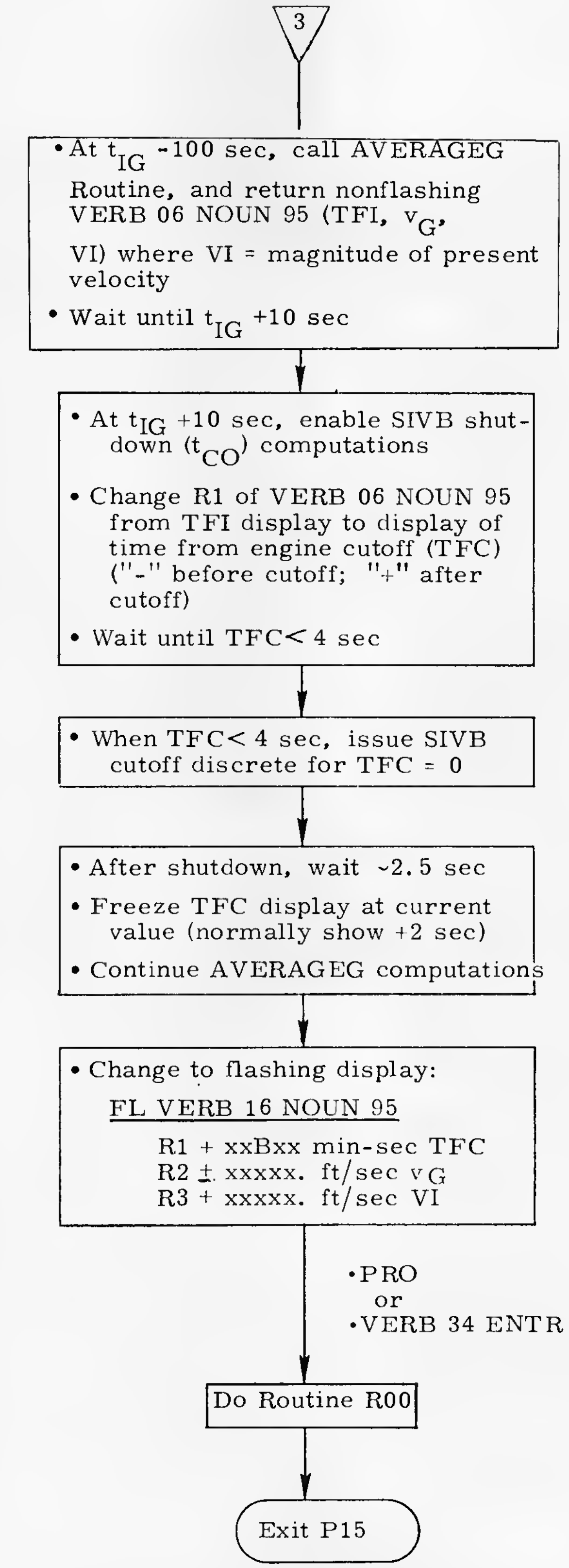

Figure 3.2.2-1. TLI Initiate/Cutoff Program (CSM P15) (Sheet 3 of 3)

3.2.2.2 Procedures

Table 3.2.2-I is a chronology of P15 DSKY procedures. An expanded version is presented here:

I. PRELIMINARY

A <u>VERB 48 ENTR</u>

Perform DAP Data Load Routine (R03) (paragraph 9.2.1). Load vehicle-configuration code 3 into R1 (position A) of NOUN 46. Load other positions as prescribed by mission procedures.

B <u>VERB 83 ENTR</u>

Perform Rendezvous Parameter Display Routine No. 1 (R31); setup ORDEAL as prescribed by mission procedures to provide FDAI reference for TLI manual backup.

II. INITIATION

A VERB 37 ENTR 15 ENTR

- Call P15 and observe flashing display of TB6 initiation time (GET):

<u>FL VERB 06 NOUN 33</u>

R1 +xxxxx. hr
R2 +oooxx. min
R3 +oxx.xx sec

- Key VERB 25 ENTR to load desired GET for TB6 initiation
- PRO

B Observe flashing display of velocity magnitude (V C/O) at TLI cutoff:

<u>FL VERB 06 NOUN 14</u>

R1 +xxxxx. ft/sec V C/O
R2 blank
R3 blank

- Key VERB 21 ENTR to load new data
- PRO

C Observe nonflashing display of time from ignition (maximum reading, 59B59; "-" before nominal ignition; "+" after nominal ignition); velocity to be gained (v_G) at TLI; and present velocity (VI):

<u>VERB 06 NOUN 95</u>

R1	±xxBxx	min-sec TFI
R2	±xxxxx.	ft/sec v_G
R3	+xxxxx.	ft/sec VI

<u>NOTE</u>.—R1 is updated every 1 sec. Velocity to be gained equals V C/O (NOUN 14) minus VI. VI is magnitude of Permanent State Vector Velocity until start of AVERAGEG when it becomes magnitude of Present Velocity.

- Monitor
- Observe UPLINK ACTY light and SII SEP light turn on at TB6 initiation time; if SII SEP light fails to turn on, place LV GUID switch in CMC position.

<u>NOTE 1</u>.—If LV GUID switch is placed in CMC position (SATURN IU self-described as failed), the CMC will assume responsibility for launch-vehicle guidance. The crew must use the RHC to provide steering signals to the SATURN autopilot during the SIVB thrusting maneuver.

<u>NOTE 2</u>.—Display update every 1 sec. At t_{IG} -105 sec, blank DSKY verb, noun and data registers; at t_{IG} -100 sec, DSKY returns, signaling start of AVERAGEG.

D When desired after start of AVERAGEG, key VERB 16 NOUN 62 ENTR and observe display of inertial velocity (VI), altitude rate (H-dot), and altitude (H):

<u>NOTE</u>.—Keying VERB 16 NOUN 62 ENTR is at crew option. If NOUN 62 is not called, VERB 06 NOUN 95 continues. Similarly, if NOUN 62 is called, keying KEY REL returns the NOUN 95 display. At t_{IG} +10 sec, Register R1 of NOUN 95 changes to contain time from engine cutoff (TFC)—"-" before; "+" after.

VERB 16 NOUN 62

R1 +xxxxx. ft/sec VI

R2 ±xxxxx. ft/sec H-dot

R3 +xxxx.x n.mi. H

- Monitor
- At t_{IG}, observe LV GUID light not on. If LV GUID light on,—

a) place LV GUID switch in CMC

b) compare NOUN 62 values with pad schedule; referencing FDAI ball, use RHC to send steering signals to SATURN autopilot.

- At t_{CO}, observe engine cutoff

NOTE.—Backup engine cutoff according to crew procedures specifying use of LV STAGE switch.

E When ready, key KEY REL and observe return of flashing VERB 16 NOUN 95:

FL VERB 16 NOUN 95

R1 ±xxBxx min-sec TFC

R2 ±xxxxx. ft/sec v_G

R3 +xxxxx. ft/sec VI

NOTE.—R1 should now be static; Register R1 normal reading, + 2 sec.

- Record
- PRO (or VERB 34 ENTR) to exit P15.

3.2.2.3 There are no program alarms associated with P15.

3.2.2.4 Restarts

P15 is restart protected.

TABLE 3.2.2-1
TLI INITIATE/CUTOFF (CMC P15) DSKY PROCEDURES (SHEET 1 OF 2)

Step	Entry	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
				I. PRELIMINARY				
A	V48 ENTR	Perform DAP Data Load Routine (R03), described in paragraph 9.2.1. Load vehicle-configuration code 3 into R1 of Noun 46.						
B	V83 ENTR	Set up ORDEAL as prescribed in appropriate crew-procedures documents.						
				II. INITIATION				
A	V37 ENTR 15 ENTR	Fl. V06 N33	15	Display TB6 initiation time (GET).	R1 + xxxxx. hr R2 + oooxx. min R3 + oxx.xx sec	• Upon crew's PRO, set up LONGCALL for TB6 time in Noun 33. • Set t_{IG} = TB6 + 9 min 37.6 sec.	• Key VERB 25 ENTR to load new data. • Key PRO to accept data.	---
B	---	Fl. V06 N14	15	Display velocity magnitude at TLI cutoff.	R1 + xxxxx. ft/sec R2 Blank R3 Blank	• Upon crew's PRO, calculate time from TLI ignition (TFI).	• Key VERB 21 ENTR to load new data. • Key PRO to accept data.	---
C	---	V06 N95	15	• Display TFI (maximum value, 59B59; "-" before nominal ignition; "+" after nominal ignition). • Display velocity to be gained (v_G) at TLI. • Display present velocity (VI)	R1 ± xxBxx min-sec TFI R2 ± xxxxx. ft/sec v_G R3 ± xxxxx. ft/sec VI	• Update display every 1 sec. • At TB6, set SIVB injection-sequence-start bit (Bit 13 of Channel 12), and turn on UPLINK ACTY light. • At TB6 +10 sec, reset SIVB injection-sequence-start bit, and turn off UPLINK ACTY light, then— • At t_{IG} -105 sec, blank DSKY. • At t_{IG} -100 sec, call AVERAGEG and return DSKY display.	• Monitor • Observe UPLINK ACTY light and SII SEP light turn on at TB6 initiation time; if SII SEP light fails to turn on, place LV GUID switch in CMC position. • When desired, key VERB 16 NOUN 62 ENTR	UPLINK ACTY light indicates that P15 has issued TB6-initiation discrete; SEP II SEP light indicates TB6 initiation. NOTE.—If SEP II light fails to come on and the LV GUID switch is placed in the CMC position, the crew must use the RHC to provide steering signals to the SATURN autopilot during SIVB thrusting maneuver. Calling VERB 16 NOUN 62 only meaningful after start of AVERAGEG.
D	V16 N62*	V16 N62	15	• Display inertial velocity (VI) • Display altitude rate (H-DOT) • Display altitude (H)	R1 ± xxxxx. ft/sec VI R2 ± xxxxx. ft/sec Ḣ R3 + xxxx.x n.mi. H	• Update display every 2 sec. • At t_{IG} +10 sec, enable SIVB shutdown (t_{CO}) computations, change R1 of V06 N95 to contain time from cutoff (TFC). ("-" before cutoff; "+" after cutoff). • When TFC < 4 sec, issue SIVB cutoff discrete for TFC = 0.	• Monitor • At t_{IG}, observe LV GUID light not on. If LV GUID light is on, — a) place LV GUID switch in CMC b) use RHC to send steering signals to SATURN autopilot. • At t_{CO}, observe engine cutoff; perform engine-cutoff backup procedures. When ready for return of N95 display, key KEY REL.	*Crew option. VERB 06 NOUN 95 continues if NOUN 62 not called. Calling VERB 16 NOUN 62 only meaningful after start of AVERAGEG

TABLE 3.2.2-I
TLI INITIATE/CUTOFF (CMC P15) DSKY PROCEDURES (SHEET 2 OF 2)

Step	Entry	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
D (cont.)						• After shutdown, wait ~2.5 sec; then freeze TFC display at current value. • Continue AVERAGEG computations.		
E	---	FL V16 N95	15	Display post-cutoff TFC (normally static at +2[illegible]), V_G, and VI	R1 _xxBxx min-sec TFC R2 ± xxxx. ft/sec V_G R3 ± xxxx. ft/sec VI	• Upon crew's PRO or VERB 34 ENTR, do Routine R00 and exit P15.	• Record • PRO (or VERB 34 ENTR) when ready.	---
F	---	FL V37 (R00)	15	Request "Please select new program"	---	---	• To select PXX, key XXE	

BLANK

3.3 LGC ASCENT PROGRAMS

The Nominal Ascent Program (P12), the Descent Propulsion System Abort Program (P70), and the Ascent Propulsion System Abort Program (P71) are essentially three initialization programs whose primary function is to supply targeting information for Ascent Guidance. After the initialization phase is completed by P12, P70, or P71, the Ascent Guidance operates independently of the program that initialized it. Figure 3.3-1 shows a nominal liftoff and Ascent Guidance profile for the J-Mission. Since predetermined phasing is not possible for aborts, there is no nominal profile for P70 or P71.

Ascent Guidance is used to insert the LM into an orbit suitable for a subsequent rendezvous with the CSM. This purpose is achieved by maneuvering the LM to a desired velocity vector at a specified altitude and distance from the CSM orbital plane. The nominal LM insertion orbit is coplanar with the CSM orbit. In P12, the crew has the option of selecting an orbital plane for the LM, which is non-coplanar with the CSM. The crew would use the plane-selection option if the indicated out-of-plane distance from the launch site to the CSM plane is too large for the allowable Δv budget. In the DPS Abort Program, P70, and the APS Abort Program, P71, the plane selection is done automatically; the distance between the LM target orbital plane and the LM position at abort is limited by a pad-loaded value.

To control the ascent maneuver to the three velocity (i.e., downrange, crossrange, and radial) and two position (i.e., crossrange and injection radius) constraints on injection, the following guidance concepts are used:

a. The engine configuration allows control in the thrust direction only (i.e., radial and crossrange position and velocity are explicitly controlled).
b. The desired velocity in the downrange position is achieved by terminating thrust at the proper time.
c. The best perfomance is achieved when the required velocity change is in the downrange direction.

Powered Ascent Guidance consists of the three major phases listed below:

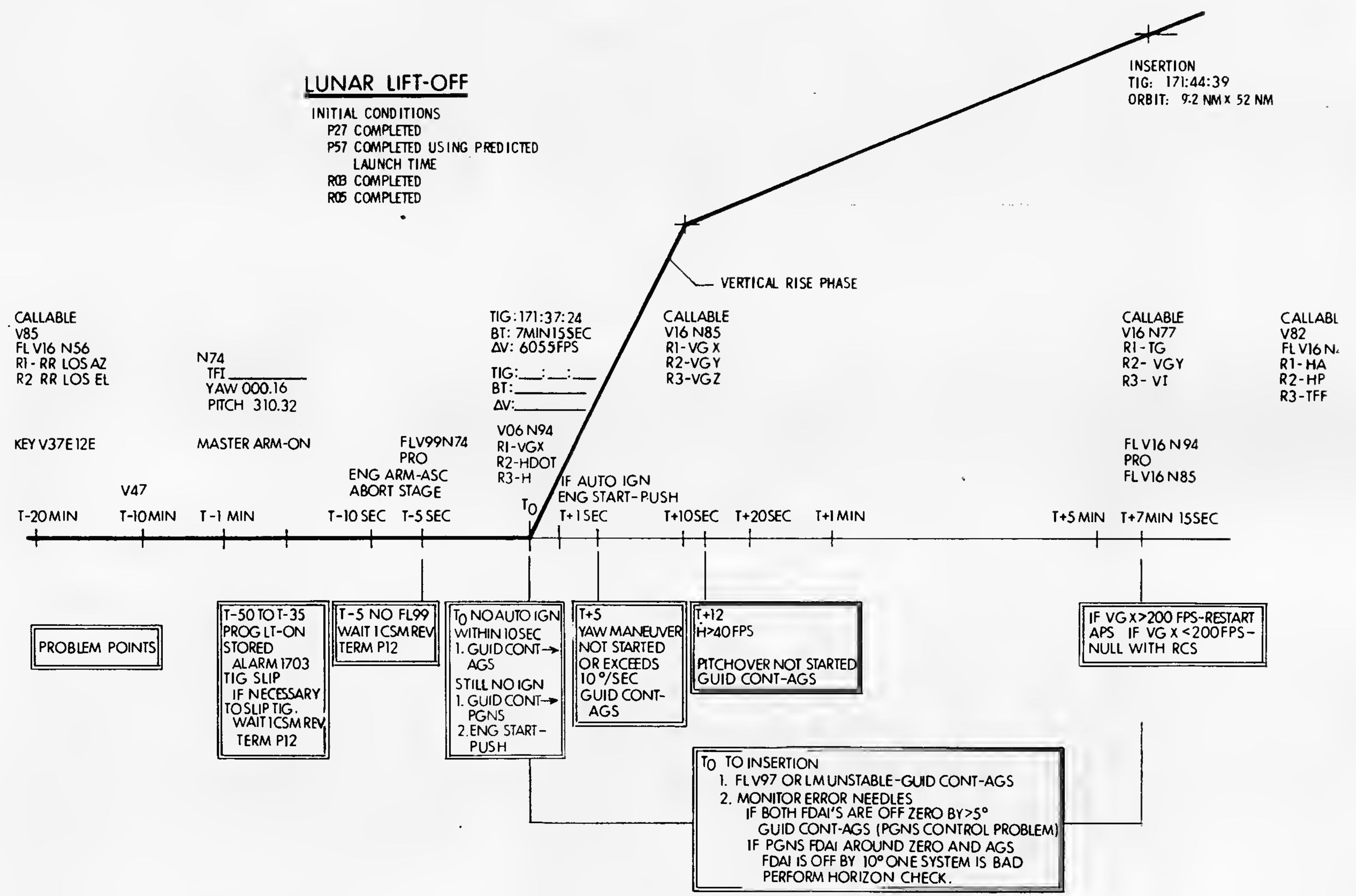

Figure 3.3-1. Nominal Liftoff and Ascent Guidance Profile (J Mission)

a. Pre-ignition phase*

b. Vertical rise phase control (divided into vertical rise and pitchover phases)

c. Ascent Guidance phase.

The Powered Ascent Guidance uses two coordinate systems in addition to the six major coordinate systems used in the navigation and guidance programs. (For a discussion of these six major coordinate systems, refer to subsection 7.1.) The first of these special coordinate systems is the Instantaneous Local Vertical Coordinate System. This system is used in the velocity control portion of the Ascent Guidance computations. The second, the Target Coordinate System, is an inertial moon-centered–pseudo-system in which one axis is an arc length. Both of these coordinate systems are illustrated in Figure 3.3-2.

The initialization phases of P12, P70, and P71 are discussed in paragraphs 3.3.1, 3.3.2, and 3.3.3, respectively.

Following initialization, when the targets are provided, Ascent Guidance enters the vertical rise phase control. The actual vertical rise phase lasts approximately 8 seconds, or until the radial velocity of the LM is greater than 40 ft/sec. The PGNCS holds the LM at an attitude at which the LM +X-axis is parallel to the LM position vector at t_{IG}. The X-axis override is inhibited during this phase.

Before APOLLO 12, the pitchover maneuver following the vertical rise was not permitted until the LM +Z-axis was within 5 deg of the horizontal component of the computed thrust vector. This restraint could delay the start of the pitchover phase, costing a substantial Δv penalty. Consequently, the test was removed. Ascent Guidance still attempts to align the Z-axis properly during the vertical rise phase, but the pitchover maneuver begins regardless of the LM orientation after the vertical rise phase is completed.

The pitchover phase of vertical rise control begins when the radial velocity exceeds 40 ft/sec. At this time, the PGNCS commands the LM to pitch down, about the Y-axis, an amount defined by the guidance equations. Note that during this pitchover

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* The pre-ignition phase applies to the Nominal Ascent Program, P12. (Refer to paragraph 3.3.1.) Both the DPS Abort Program (P70) and the APS Abort Program (P71), however, have an initialization phase before entering the vertical rise or Ascent Guidance phases.

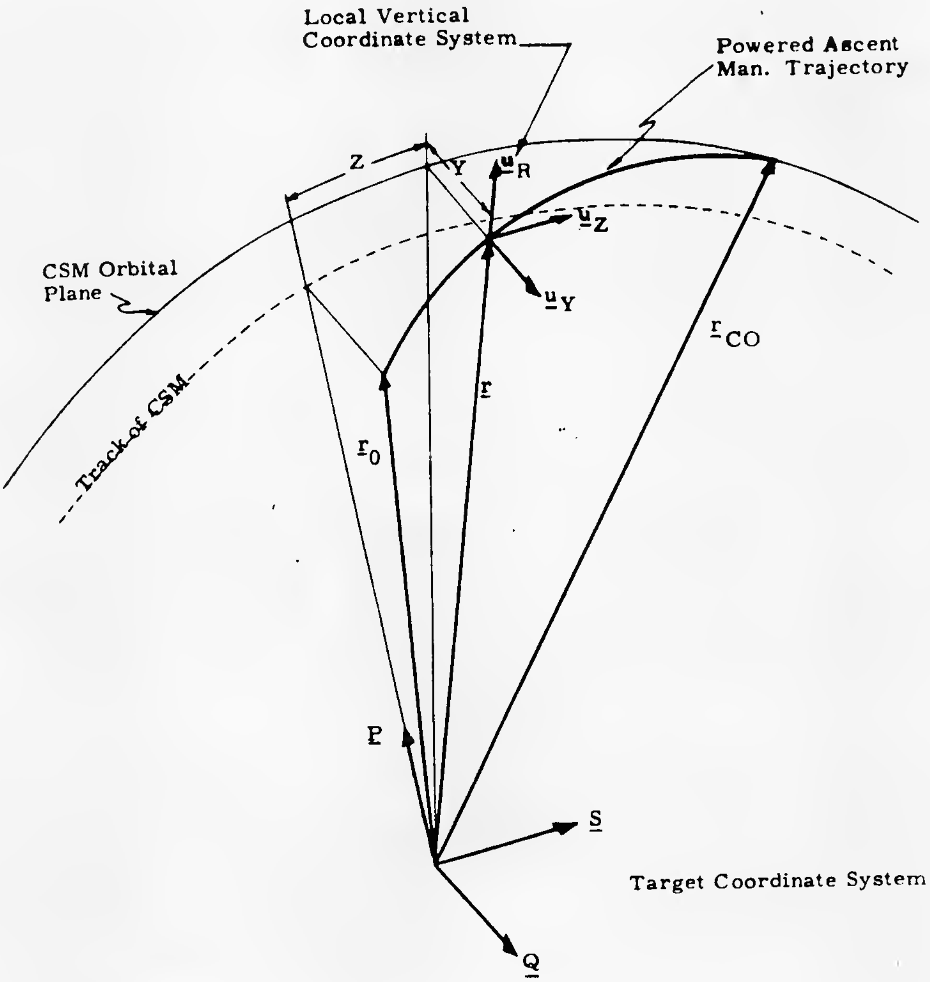

Figure 3.3-2. Powered Ascent Guidance Coordinate Systems

maneuver, the X-axis override option available to the crew is inhibited until 12 seconds after completion of the vertical rise phase.*

The vertical rise and pitchover maneuvers of the vertical rise phase control portion of Ascent Guidance also apply to both the DPS Abort Program (P70) and the APS Abort Program (P71), with additional restraints controlling the vertical rise phase.

If the abort is initiated at an altitude greater than 25,000 ft, no vertical rise is used and the abort maneuver enters directly into the Ascent Guidance phase. If the abort takes place at an altitude less than 25,000 ft, the vertical rise phase is entered.

The vehicle attitude during Ascent Guidance is controlled by FINDCDUW, which is the interface program converting the thrust vector commands of Ascent Guidance to CDU angles for the DAP (Digital Autopilot). Before calling FINDCDUW, the Ascent Guidance equations check to determine if the commanded maneuver will take the LM +X-axis through the downward vertical. If so, the command is replaced by a command to vertical thrusting until the +X-axis is within 30 deg of the upward vertical, or 90 deg of the computed command.

Ascent Guidance is essentially used in the same way by P12, P70, and P71. The notable differences are that the abort programs provide continuous targeting throughout Ascent Guidance, whereas P12 provides fixed targets at the start.

The Ascent Guidance equations use the targets (i.e., ZDOTD, RDOTD, YD, YDOTD, and RD) to determine in which direction to point the thrust vector. The Ascent Guidance phase is initiated after vertical rise is completed. The computational sequence is initiated by the Servicer routine and is repeated every 2 seconds. Briefly, the computational sequence is as follows. The existence of an "engine on" command is checked, and the velocity increment measured by the PIPAs over the last computational cycle is compared to the established minimum value. This thrust filter bypass computation is performed in addition to the Thrust Monitor Routine (R40). If the engine thrust test is successful, the thrust filter computation, which smooths out the PIPA results by averaging several successive PIPA Δv readings, is processed.

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* Actual inhibition time is ten seconds, although two seconds pass after inhibition is completed, before the X-axis override can be used.

After the thrust filter computations are completed, the following parameters are computed every 2 seconds:

a. Local vertical coordinate system
b. Local velocity components
c. Local position computation (i.e., radial and crossrange positions)
d. Velocity-to-be-gained
e. Time-to-go estimation
f. Engine-off test.

When the t_{go} (time-to-go) falls below 2 seconds, no new Ascent Guidance coefficient computations are made. The remainder of the maneuver is performed using the previously computed values.

3.3.1 P12, Nominal Ascent Program—LGC

P12 is basically an initialization program with the following two functions:

a. To supply targets for the Ascent Guidance

b. To initialize the required engine parameters for the Ascent Guidance.*

The program controls the nominal LM ascent from the lunar surface, but can also be used when an early liftoff is necessary—after the Landing Confirmation Program (P68) has been selected.

The crew selects P12 by keying in VERB 37 ENTR 12 ENTR, allowing sufficient time (at least 5 minutes) to complete the pre-ignition phase.

For the early liftoff, the target values used are the same as those used for the late and lunar-surface aborts, P70 and P71 (i.e., downrange velocity (ZDOTD) = 5509.5 fps; radial velocity (RDOTD) = 19.5 fps) to save time. For the nominal liftoff, however, the crew must change these values by DSKY inputs.

3.3.1.1 Nominal Liftoff

For a nominal ascent, the crew calls P12 far enough ahead of time to permit recognition and response to the following displays:

a. Time of ignition (t_{IG}). This should be set at the desired liftoff time since a lunar surface alignment has already been performed.

b. Targets—downrange velocity, radial velocity, and crossrange. Nominally, the crew changes the downrange and radial velocities.

c. FDAI angles and time from t_{IG}. FDAI readings to be expected by the crew after pitchover and countdown to t_{IG}.

3.3.1.2 Early Liftoff

If a LM system malfunction, such as an APS propellant leak, is discovered, an early liftoff is carried out. For an early liftoff, the crew sets t_{IG} close enough to the current time to permit sequencing through the above displays without DSKY inputs. A typical flight-plan procedure is shown below: (Note that t_{IG} has been set at 1380 sec.)

* For a detailed explanation of the Ascent Guidance as it relates to P12, refer to subsection 3.3.

EVENT	TIME FROM IGNITION (PDI IGNITION)
Touchdown	690-775 sec (711 is nominal)
STAY/NO-STAY	780 sec
VERB 37 ENTR 68 ENTR	980 sec
VERB 37 ENTR 12 ENTR	990 sec (P12 must be selected at least 5 minutes before ignition, i.e., by PDI+1080.)
GO/NO-GO for P12	1375 sec
Liftoff	1380 sec

If, at sometime during the above procedure, the decision is made to stay, the crew terminates P12 and then proceeds with lunar-surface operations such as alignment (P57).

3.3.1.3 Targeting

The objective of targeting is to set up a group of conditions necessary to achieve a suitable injection trajectory to complete the rendezvous maneuver. The necessary targeting parameters for P12 depend on whether P12 is used in a nominal ascent or in an early liftoff. It is important to note here that in a nominal ascent of P12 there is a 400-ft overshoot to orbit injection.

VGX is now available in the normal ascent display of NOUN 94; to monitor all three $\underline{v}_G$ components, the crew can call NOUN 85. To monitor TG, the crew can call NOUN 77. This information allows the crew to decide whether or not to null out the residuals (after the burn) by using the RCS jets to achieve the targets.

The injection targeting parameters for P12 that are stored in the LGC are as follows:

a. ZDOTD (downrange velocity)
b. RDOTD (radial velocity)
c. T_{IG} (time of ignition)
d. $Y_D = 0$ (desired injection out-of-plane distance measured from the CSM orbital plane)
e. R_D (desired injection radius; nominally 60,000 ft larger than the landing-site radius)
f. YDOTD (desired injection crossrange velocity) = 0

RDOTD, ZDOTD and crossrange (related to Y_D) are displayed to the crew via VERB 06 NOUN 76. In the nominal ascent, during pre-ignition, the crew modifies the

first 2 parameters by keying in the following values in response to VERB 06 NOUN 76:

a. ZDOTD = velocity corresponding to a 52-n. mi. apolune orbit
b. RDOTD = approximately 32.0 ft/sec radial velocity.

The crew must enter the above two values during each use of P12 for nominal ascent. The crew also has the option of changing crossrange if the stored crossrange value (required to achieve $Y_D = 0$) is large enough to strain the Δv budget. A crossrange value should not be specified, however, that causes the ascent trajectory to cross through the CSM orbital plane. Note that the initially displayed value of crossrange will be the distance between the LM position vector at t_{IG} and the CSM orbital plane, (i.e., the total out-of-plane maneuver vector at t_{IG} required during the ascent to make the LM and CSM orbits coplanar). The remaining stored parameter values are not modified for the nominal ascent.

In an early liftoff, none of the injection parameters stored in the LGC are modified by the crew because of a lack of time. These prestored injection parameters control the ascent maneuver to cutoff (see paragraph 3.3.1.9, below) at an altitude of approximately 60,000 ft, resulting in a 30-n. mi. apolune. Then, the ground supplies data for the crew to perform a P30-P41 boost maneuver at perilune to change the apolune from 30 to 52 n. mi., making the early liftoff apolune equivalent to that of a nominal ascent.

3.3.1.4 Related Routines and Extended Verbs

Following is a list of related routines associated with P12, and a brief explanation of each.

a. R02 is the IMU Status Check Routine.
b. R10 is the Landing Analog Display Routine. (Refer to paragraph 3.3.2.2.1 for a detailed explanation of R10.)
c. R41 is the State Vector Integration Routine. (Refer to paragraph 6.3.1.2.2 for an explanation of R41.)
d. R47 is the AGS Initialization Routine.* (Refer to paragraph 3.3.2.2.4 for an explanation of R47.)
e. R40 is the Thrust Fail Routine and monitors APS engine thrust failure.*
f. R03 is the DAP Data Load Routine.*

* R40 is called automatically following ignition; R03 is called before P12 is entered; and R47 is called after P12 by keying VERB 47 ENTR into the DSKY.

Table 3.3.1-I lists the extended verbs that can be used in P12.

3.3.1.4.1 DPS/APS Thrust Fail Routine (R40).—The Thrust Fail Routine, R40, monitors the IMU PIPA outputs for evidence of DPS or APS thrust failure. R40, automatically called by Servicer during P12, initiates engine-fail procedures if the monitor indicates a lack of thrust during engine on; that is, engine thrust remains below a given level for five cycles of the Δv monitor following ignition or during a thrusting maneuver if the engine thrust falls below a given level for 2 cycles. After liftoff, if R40 fails to recognize APS thrusting, Ascent Guidance will inhibit guidance steering and zero attitude rates. This failure would be indicated to the crew by a flashing VERB 97 NOUN 94 display. If the PGNCS is not controlling the spacecraft properly at this time, the crew can switch to the AGS. First, however, the crew should verify that the failure is genuine. If the failure is not genuine, the PRO response to the flashing VERB 97 NOUN 94 display terminates the display.

The following is a list of responses to the flashing VERB 97 NOUN 94 display:

a. The crew can, by keying PRO, re-initialize and re-enable the Δv monitor to check again whether there is sufficient thrust.

b. The crew can, by keying ENTR, return to the point in the program sequence at the flashing VERB 99 display in P12. The crew then has the following two options:

    1. To key ENTR to the flashing VERB 99 display in order to trim.
    2. To key PRO to the VERB 99 display to attempt to re-ignite the APS.

A peculiarity of R40 results if the APS engine does not ignite at liftoff. The LGC does not detect the absence of APS thrust as an engine thrust failure. Consequently, the flashing VERB 97 NOUN 94 display will not appear after this failure to ignite, no matter how long the failure persists.

The responses to the VERB 97 NOUN 94 display are not appropriate when the APS fails to ignite on the lunar surface. The Δv monitor does not consider lunar-surface engine failure to be genuine, because the PIPAs are measuring the lunar gravity thrust of the surface against the LM. The APS threshold of 308 PIPA pulses over a 2-second period is below the magnitude of one lunar g ($1.62\ m/sec^2$ = lunar g; $1.54\ m/sec^2$ = threshold value). Figure 3.3.1-1 flowcharts R40.

TABLE 3.3.1-I

EXTENDED VERBS USED WITH LM P12 (SHEET 1 OF 4)

VERB	Identification	Purpose	Remarks
60 ENTR	Display PGNCS—derived vehicle attitude rates.	Display on the FDAI error needles the PGNCS—derived attitude rates.	This process may be selected at any time during P12. Vehicle rates are available, however, when the DAP is turned on.
61 ENTR	Display Mode I DAP attitude errors.	Display on the FDAI error needles the difference between the current CDU and the DAP command angles.	This process can be selected by the crew any time during P12. The crew can use Mode I error display to monitor the DAP's ability to track automatic steering commands.
62 ENTR	Display Mode II total attitude errors.	Display on the FDAI error needles the total attitude error - (NOUN 22) desired ICDU angles minus (NOUN 20) present ICDU angles.	This process can be selected by the crew any time during P12. The crew can use Mode II error display to assist them in manually maneuvering the LM.
76 ENTR	Minimum Impulse Command Mode.	Enables the Minimum Impulse Mode of the DAP. The crew can then perform manual attitude control about all the vehicles axes with the ACA in the Minimum Impulse Mode. In addition RCS jet firings are discontinued on the lunar surface with the MODE CONT switch in ATT HOLD.	Extended VERB 76 can be selected by the crew at any time.* The crew must put the GUID CONT switch to PGNS and the MODE CONT switch to ATT HOLD.

* In particular on the lunar surface. P68, the Landing Conformation Program does an automatic Verb 76.

TABLE 3.3.1-I

EXTENDED VERBS USED WITH LM P12 (SHEET 2 OF 4)

VERB	Identification	Purpose	Remarks
(76 cont)			The Minimum Impulse Mode will remain enabled until canceled by the rate command mode selection (Extended VERB 77) or a fresh start. The Rate Command Mode is also automatically established at P12 ignition. It is strongly recommended that no powered flight maneuver be attempted in this Minimum Impulse Mode.
77 ENTR	Rate Command and Attitude Hold Mode.	Enables the Rate Command Mode of the DAP and sets the desired ICDU angles equal to the actual ICDU angles. The crew can then perform manual attitude maneuvers about all vehicle axes with the ACA in the RateCommand Mode.	Extended VERB 77 can be selected by the crew at any time. The Rate Command Mode will remain enabled until canceled by the Minimum Impulse Mode (see Extended VERB 76). The GUID CONT and MODE CONT switches should be set in the same way as in Extended VERB 76. The Rate Command Mode is established at DPS ignition in P63 and is automatically established in P12 at t_{IG}.

TABLE 3.3.1-I

EXTENDED VERBS USED WITH LM P12 (SHEET 3 OF 4)

VERB	Identification	Purpose	Remarks
82 ENTR	Orbital Parameter Display Routine (R30).	Provides the crew with pertinent orbital parameters computed by the LGC, updated every 2 seconds during AVERAGEG, to supplement orbital information provided by the ground.	Extended VERB 82 is manually selected by the crew after the engine is shut down in P12 and the LM has achieved an orbit. If TFF is not computable (perilune altitude is greater than 35,000 ft) the LGC will set TFF equal to -59B59, compute TF PER and store it in NOUN 32, which the crew can also call.

TABLE 3.3.1-I

EXTENDED VERBS USED WITH LM P12 (SHEET 4 OF 4)

VERB	Identification	Purpose	Remarks
85 ENTR	Display RR LOS azimuth and elevation.	To display RR antenna azimuth and elevation to the crew via VERB 16 NOUN 56 on the DSKY.	This process is selected by the crew any time another extended verb is not active. The crew should note that if the RR is not in the AUTO mode the displayed angles may be incorrect due to the difference between the RR CDU and the RR resolve power supply phasing. When the RR POWER ON-AUTOBIT (bit 2 of channel 33) shows that the RR circuit breaker is pulled or the RR switch is in AUTO TRACK or SLEW, then the Zero RR CDU bit (bit 1 of channel 12) is set.

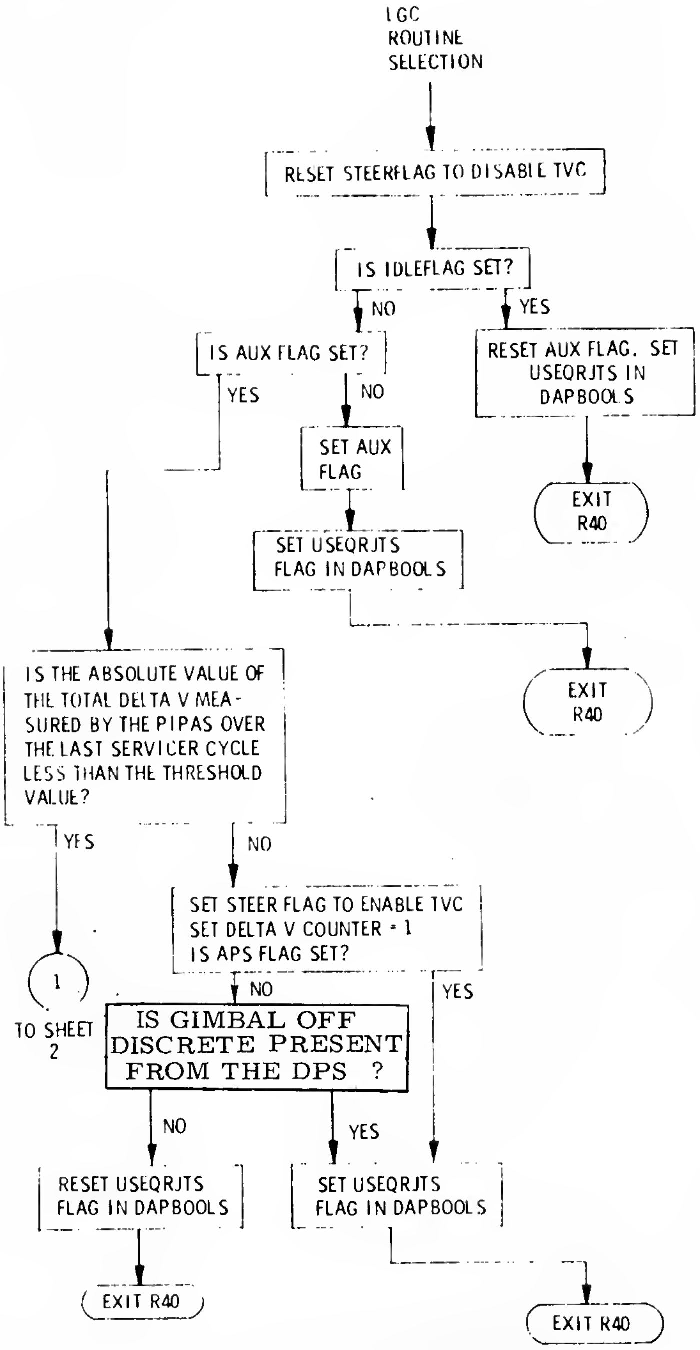

Figure 3.3.1-1. DPS/APS Thrust Fail Routine (LM R40) (Sheet 1 of 3)

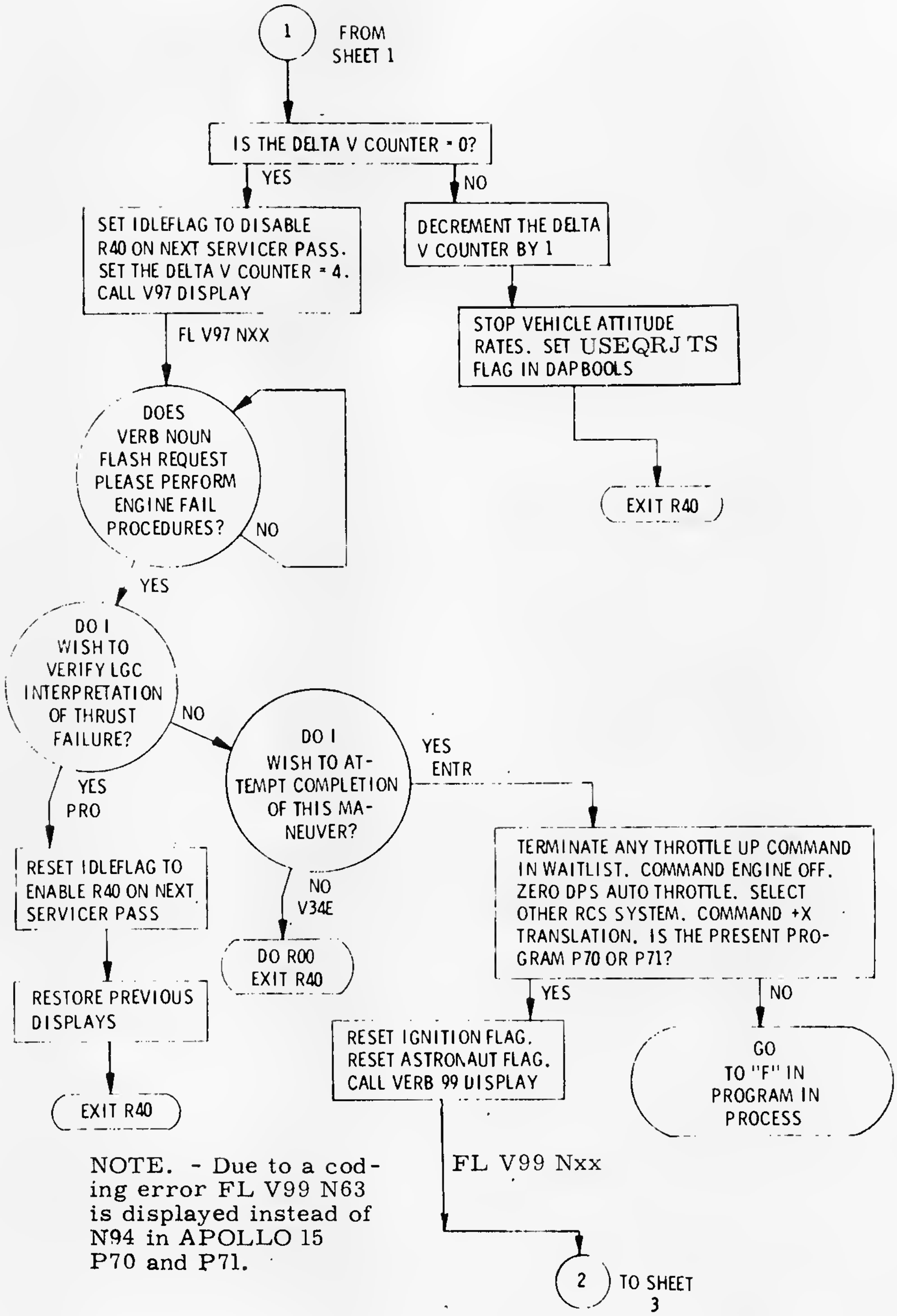

Figure 3.3.1-1. DPS/APS Thrust Fail Routine (LM R40) (Sheet 2 of 3)

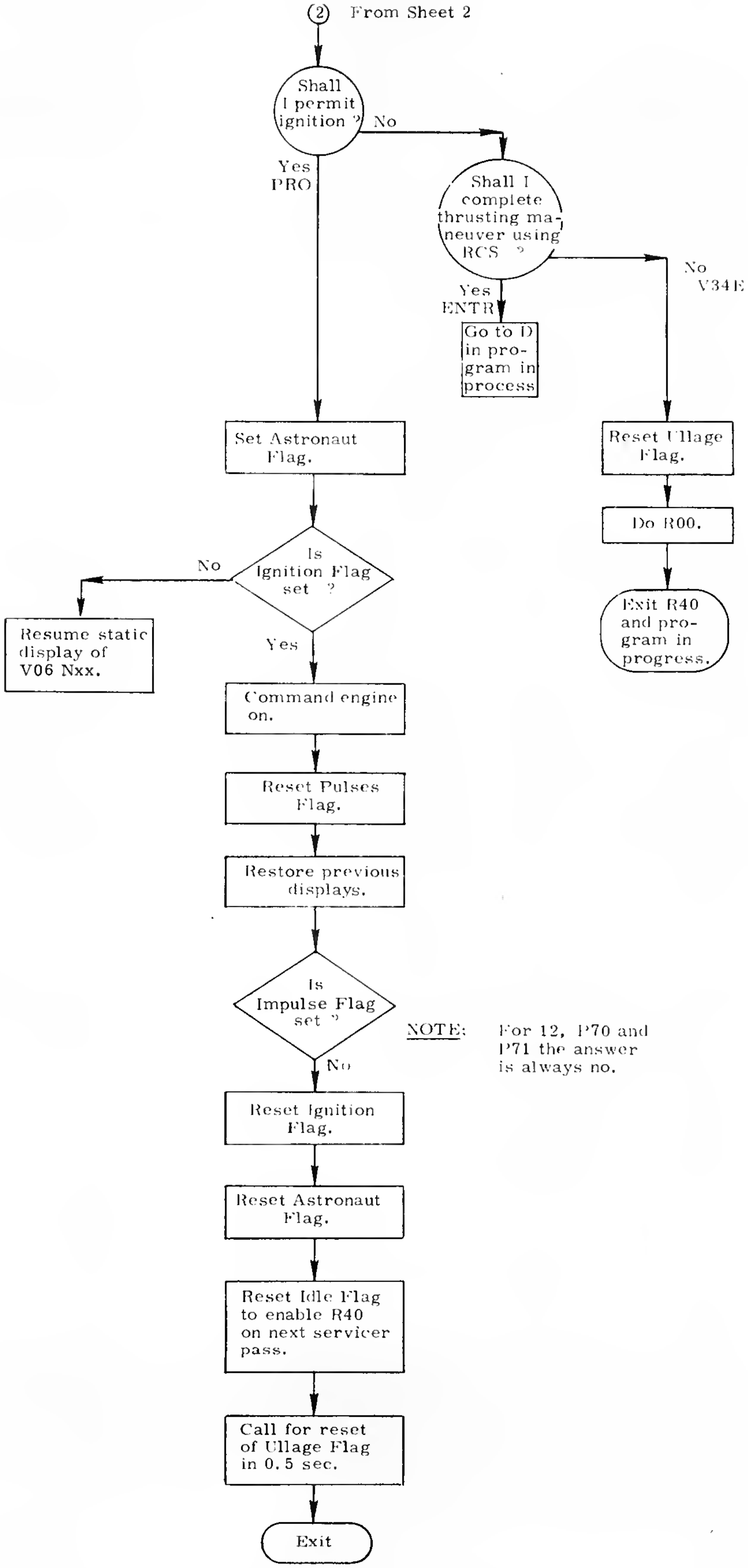

Figure 3.3.1-1. DPS/APS Thrust Fail Routine (LM R40) (Sheet 3 of 3)

3.3.1.5 Computational Sequence

Before selecting P12, the crew must perform the following:

a. Update the LM and CSM state vectors in the PGNCS using either P22 or P27, and in the AGS using R47.
b. Align the IMU using P57.
c. Align the AGS to the PGNCS to allow ground control to monitor the gyro drift performance of both systems.
d. Perform the DAP Data Load Routine (R03).

Approximately 5 minutes before liftoff, the crew selects P12 and the pre-ignition phase of P12 begins. Table 3.3.1-II lists the displays for P12. Figure 3.3.1-2 gives the logical flow of P12.

The crew calls P12 by keying VERB 37 ENTR 12 ENTR into the DSKY. P12 then checks on the availability of the IMU using the IMU Status Check Routine (R02). If the IMU is not on, or the orientation is not known, an alarm occurs. The crew can interrogate this alarm by keying VERB 05 NOUN 09 ENTR. The DSKY displays alarm code 00210 if the IMU is not on, and alarm code 00220 if the orientation is unknown. If either alarm occurs, the crew should follow the procedure described in paragraph 3.3.1.6.

The crew then sees the flashing VERB 06 NOUN 33 display containing the t_{IG} value on the DSKY. If the t_{IG} is satisfactory, the crew records it and keys in PRO to continue. To update the displayed value of t_{IG}, the crew keys VERB 25 ENTR and loads R1, R2 and R3 with the new value of t_{IG} before keying PRO.

Following the computation of targeting information by the LGC, the DSKY displays —via the flashing VERB 06 NOUN 76—downrange velocity, radial velocity, and crossrange in R1, R2 and R3, respectively, for crew approval. To accept the values displayed on the DSKY, the crew keys PRO and P12 continues. In a nominal liftoff, however, the crew updates the values of downrange and radial velocity for the ascent maneuver by keying VERB 24 ENTR and loading the new values in R1 and R2 before keying PRO to continue. The crew now also has the option of specifying a new value for the crossrange displayed in R3 by keying VERB 23 ENTR and loading R3. After the target information has been updated in the LGC, the crew should check that the GUIDANCE CONT switch is set to PGNS and the spacecraft PGNS switch on the MODE CONT panel is in AUTO. If the switches are not set as indicated, a flashing VERB 50 NOUN 25 display appears, with R1 having a value of 00203,

TABLE 3.3.1-II

DISPLAYS ASSOCIATED WITH

NOMINAL ASCENT (LM P12) (SHEET 1 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
FL V37	R00	Request astronaut to select program	---	---
V05 N09 E	Astronaut (in R02)	Verify program alarm	00210 = ISS not on 00220 = IMU orientation unknown	R1 R2 { xxxxx* R3
FL V06 N33	P12	Display time of APS ignition for ascent for approval and/or update	Time of liftoff in hrs, mins, secs	R1 ooxxx hrs R2 oooxx min R3 oxx.xx sec
V25 E	Astronaut	Load desired t_{IG} (AS)	---	R1 ooxxx hrs R2 oooxx min R3 oxx.xx sec
FL V06 N76 ** or V06 N76 E	P12 or astronaut	Display target parameters for approval and/or update	ZDOTD-downrange velocity RDOTD-radial velocity *** Crossrange	R1 xxxx.x fps R2 xxxx.x fps R3 xxxx.x n.mi.
V24 E	Astronaut	Change downrange and radial velocity data	---	R1 xxxx.x fps R2 xxxx.x fps (R3 unchanged)
V23 E	Astronaut	Change crossrange to reduce amount of delta R for the ascent maneuver	---	R1 unchanged R2 unchanged R3 xxxx.x n.mi.
FL V50 N25	P12	Request desired modes be selected as follows: GUID CONT → PGNS ATT CONT → AUTO	ENTR = bypass request PRO = accept request by changing modes first	R1 00203_8 R2 Blank R3 Blank

*Refer to note in paragraph 3.3.1.6.

**Can be called in P12 after t_{IG}. Any change to R3 (crossrange) is not effective after the automatic display appears.

***ZDOTD can also be referred to as horizontal velocity; RDOTD as vertical velocity.

TABLE 3.3.1-II

DISPLAYS ASSOCIATED WITH

NOMINAL ASCENT (LM P12) (SHEET 2 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
V06 N74	P12	Display for comparison with actual values	TFI-time from ignition (counted down) Yaw-predicted FDAI yaw angle at maneuver completion Pitch - predicted FDAI pitch angle at maneuver completion	R1 xxBxx min, sec R2 xxx.xx deg R3 xxx.xx deg
V05 N09 E	Astronaut (R41)	Verify program alarm in R41	01703 - t_{IG} slipped during state vector integration	R1 R2 R3 { 01703 *
FL V99 N74	P12	Please perform APS engine on enable at t_{IG} - 5 sec	Same displays as V06 N74	R1 xxBxx min, sec R2 xxx.xx deg R3 xxx.xx deg
V06 N94	P12 (nominal display)	Display parameters for monitoring during entire APS burn	VGX - x-component of LM velocity-to-be-gained HDOT-rate of altitude change H - altitude	R1 xxxx.x fps R2 xxxx.x fps R3 xxxxx ft
V05 N09 E	Astronaut (FINDCDUW routine)	Verify program alarm	00401 - desired middle gimbal angle exceeds 70 deg. 00402 - FINDCDUW not controlling attitude	R1 R2 R3 { xxxxx*

* Refer to note in paragraph 3.3.1.6.

TABLE 3.3.1-II

DISPLAYS ASSOCIATED WITH

NOMINAL ASCENT (LM P12) (SHEET 3 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
FL V16 N94	P12	Informs crew of APS engine shutdown	Same as V06 N94	R1 xxxx.x fps R2 xxxx.x fps R3 xxxxx ft
FL V16 N85* or V16 N85E	P12 or astronaut*	Monitor v_G components during APS burn; after APS shutdown monitor v_G residuals during RCS trimming	VGX - X-component of $\underline{v}_G$ VGY - Y-component of $\underline{v}_G$ VGZ - Z-component of $\underline{v}_G$	R1 xxxx.x fps R2 xxxx.x fps R3 xxxx.x fps
V16 N77E	Astronaut	Display additional components to be used in monitoring APS engine shutdown	TG - estimated time of flight from present to injection (- polarity) VGY - Y-component of $\underline{v}_G$ VI - magnitude of LM inertial velocity	R1 xxBxx min, sec R2 xxxx.x fps R3 xxxx.x fps
V85 E giving FL V16 N56	Astronaut	Display RR LOS azimuth and elevation before t_{IG}	<u>Azimuth</u> - angle between LM X, Z plane and the RR LOS vector <u>Elevation</u> - angle between the LM +Z-axis and the projection of the RR LOS vector on the LM X, Z plane	R1 xxx.xx deg R2 xxx.xx deg R3 Blank

*V16 N85 can be called anytime after t_{IG} to monitor v_G components during the APS burn.

TABLE 3.3.1-II

DISPLAYS ASSOCIATED WITH

NOMINAL ASCENT (LM P12) (SHEET 4 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
V82 E *	Astronaut	To call R30, the Orbital Parameter Display routine	---	---
FL V16 N44	R30	Display orbital parameter information to supplement ground information	Apolune altitude of LM orbit Perilune altitude of LM orbit Time of free fall to 35,000 ft ***	R1 xxxx.x n.mi. R2 xxxx.x n. mi R3 xxBxx min, sec
(FL) V06 N32 E ** or (FL) V16 N32 E	Astronaut	Display time from perilune	TF perilune	R1 ooxxx hr R2 oooxx min R3 oxx.xx sec

* VERB 82 can be keyed in after APS engine shutdown (i.e. after V16 N94)

** NOUN 32 display flashes if keyed in over a flashing display. V06 or V16 can be used to call the NOUN 32 display.

*** If TFF is not computable, i.e., perilune exceeds 35,000 ft., the LGC sets TFF to -59B59 and computes TF perilune storing it in the NOUN 32 display.

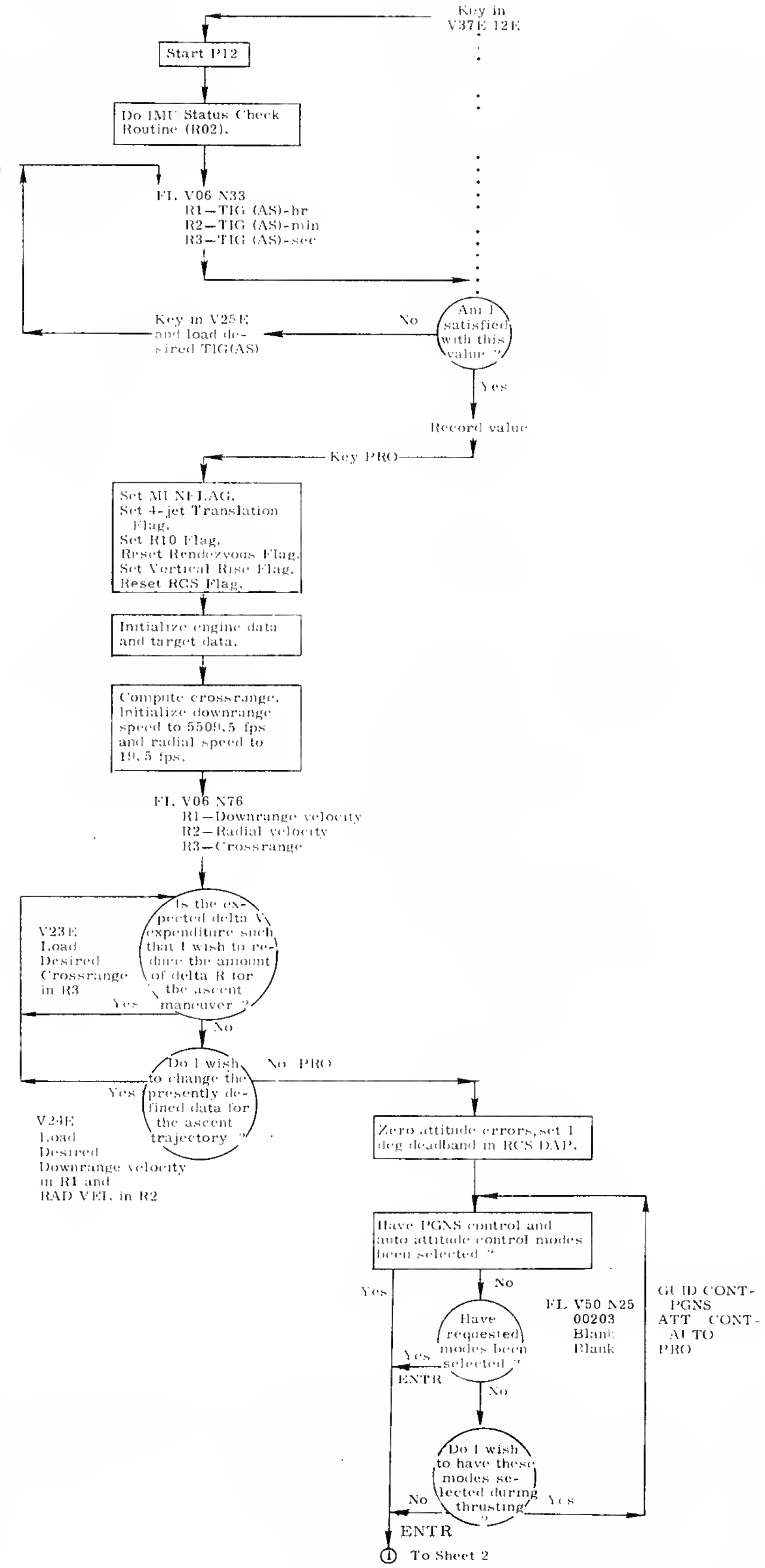

Figure 3.3.1-2. Nominal Ascent Program (LM P12) (Sheet 1 of 5)

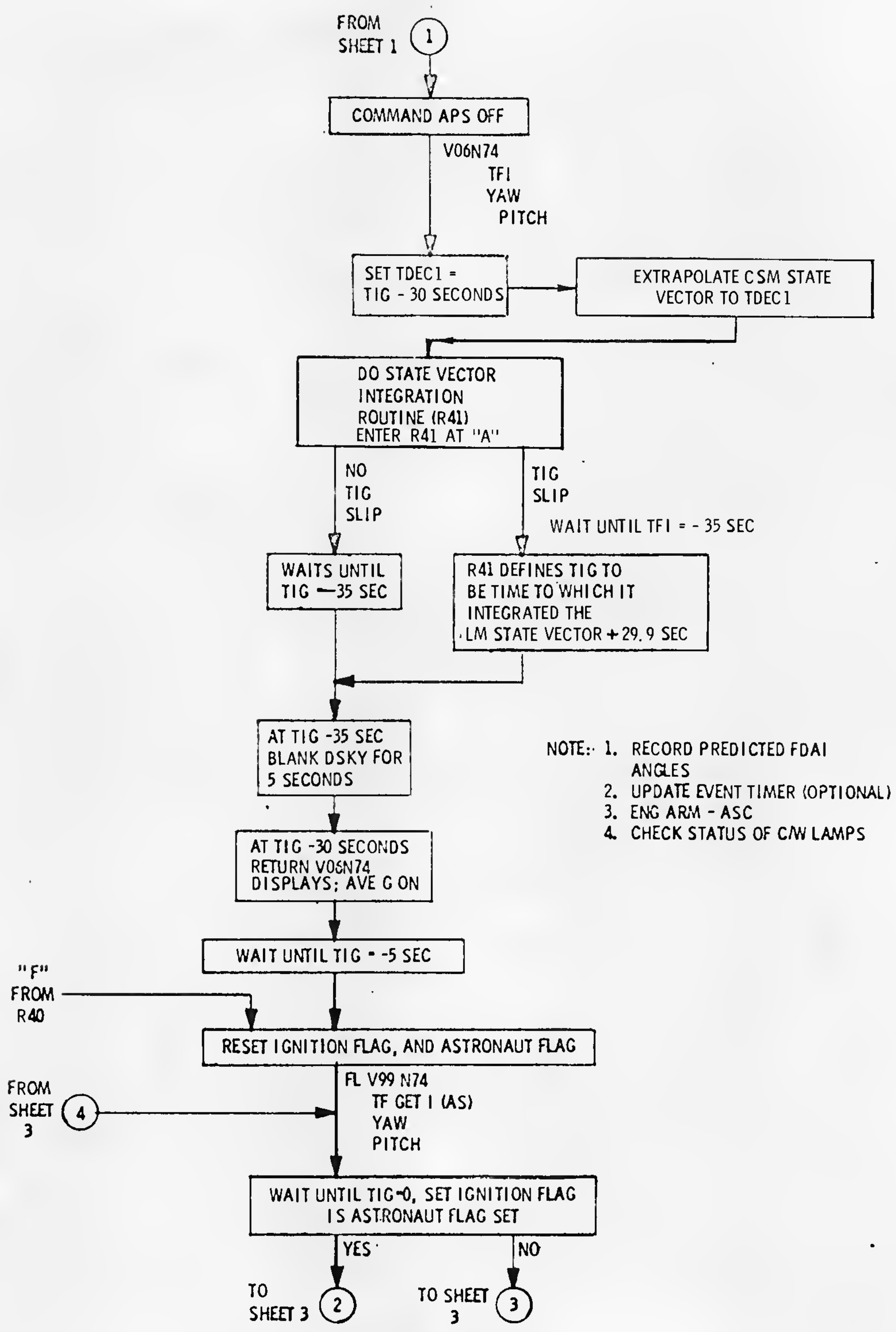

Figure 3.3.1-2. Nominal Ascent Program (LM P12) (Sheet 2 of 5)

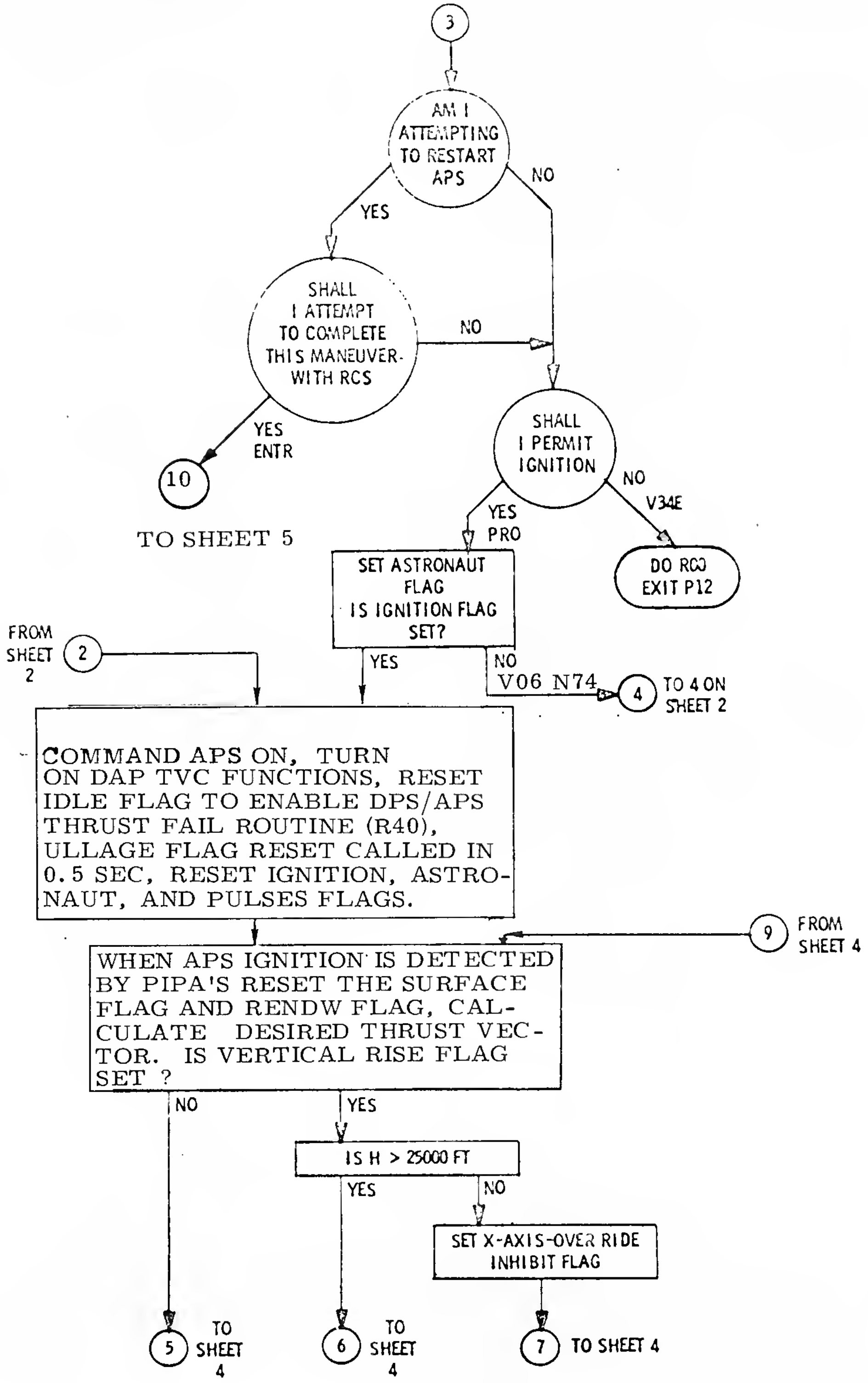

Figure 3.3.1-2. Nominal Ascent Program (LM P12) (Sheet 3 of 5)

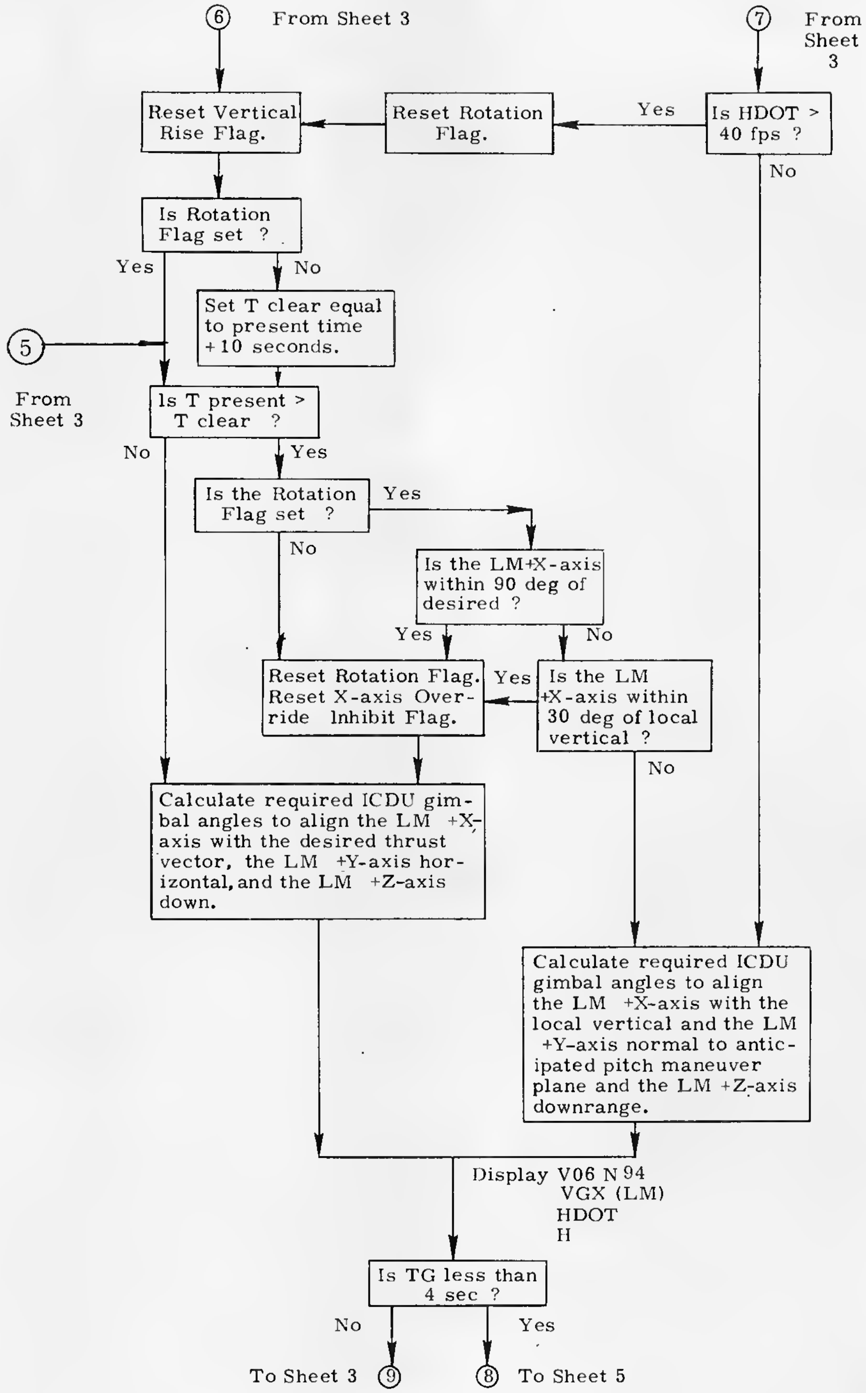

Figure 3.3.1-2. Nominal Ascent Program (LM P12) (Sheet 4 of 5)

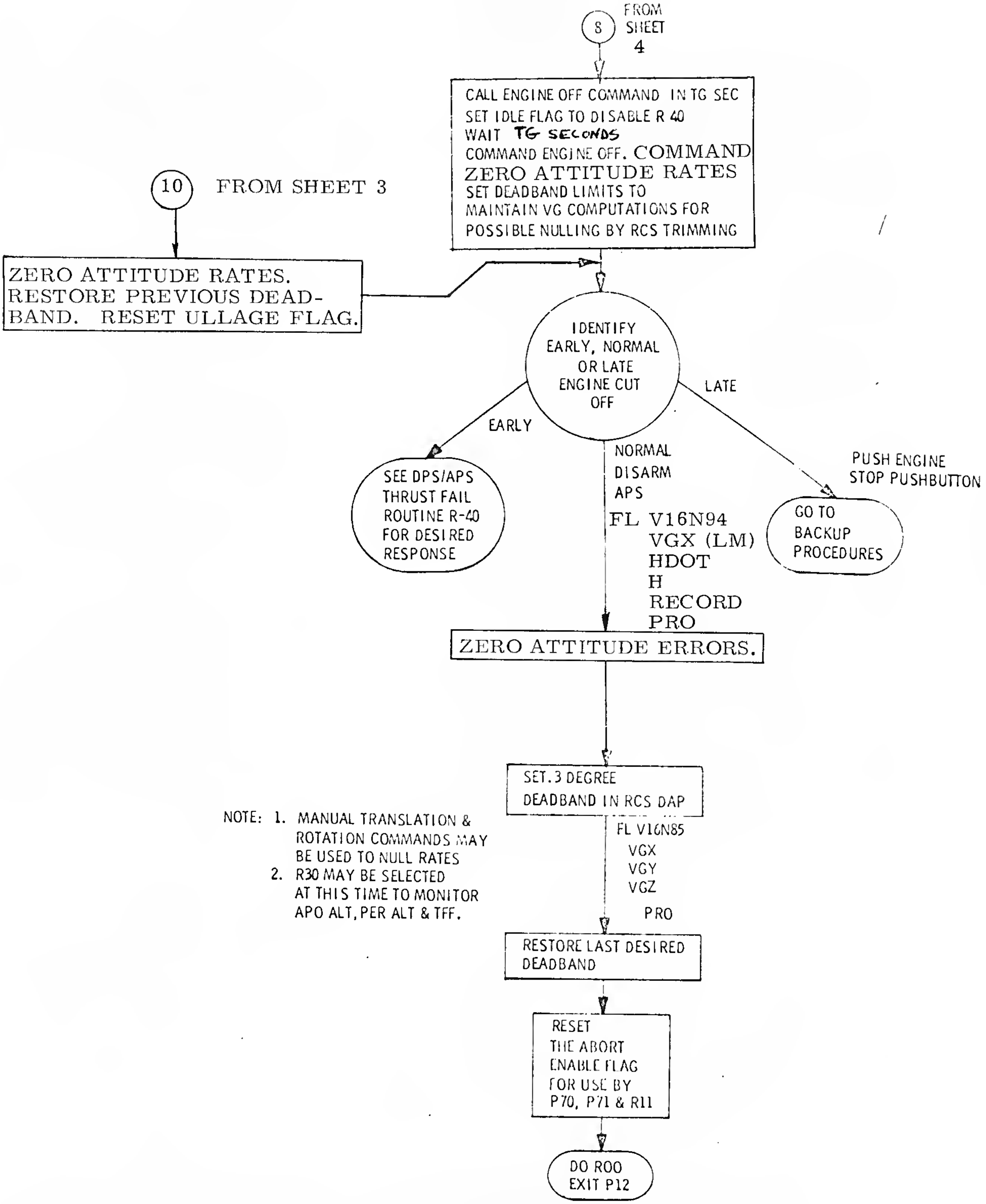

Figure 3.3.1-2. Nominal Ascent Program (LM P12) (Sheet 5 of 5)

requesting that the crew perform the above settings. If the request is to be rejected, the crew can key ENTR to allow P12 to continue. To change modes, the crew performs the settings and keys PRO.

The next display on the DSKY is the non-flashing VERB 06 NOUN 74 display of TFI, the predicted FDAI yaw, and predicted FDAI pitch angles during the early phases of Ascent Guidance. (Refer to subsection 3.3 for a description of the two early phases of Ascent Guidance.) The crew monitors the NOUN 74 display—in particular the TFI value. During the countdown phase, the LGC CMPTR ACTY light will go on indicating that the State Vector Integration Routine (R41) has been called to update the state vector. If the t_{IG} is slipped during R41 computations, the PROG alarm light illuminates. If the crew keys VERB 05 NOUN 09 ENTR, alarm code 01703 appears indicating that t_{IG} has been slipped. The crew should follow procedures defined in paragraph 3.3.1.6 on alarms. At t_{IG}-35 seconds, the DSKY blanks for five seconds and returns at t_{IG}-30 with the static VERB 06 NOUN 74 display indicating to the crew that AVERAGEG integration has started. Then, at t_{IG}-5 seconds, the DSKY changes from VERB 06 to a flashing VERB 99. This is a request to the crew to please perform engine on enable. If ignition is not desired, the crew can terminate P12 by keying VERB 34 ENTR into the DSKY. If ignition is desired, the crew performs the engine on enable by placing the ENG ARM switch on the ENGINE THRUST CONT panel in the ASC setting, and keys PRO, returning the DSKY to the VERB 06 NOUN 74 display until ignition takes place. When TFI is zero, the crew depresses the ABORT STAGE and the START pushbuttons to protect against single-point engine shutdown failure.

At liftoff and during the entire APS burn in P12, the Thrust Fail Monitor Routine (R40) is active in order to detect any thrust failures and initiate engine thrust fail procedures. If the LGC detects thrust failure, a flashing VERB 97 appears on the DSKY. The crew can then key PRO to verify the failure, ENTR to complete the maneuver with RCS propulsion, or VERB 34 ENTR to terminate P12. (A more detailed explanation of the responses is given in paragraph 3.3.1.4.1.) The crew can also key VERB 37 ENTR 00 ENTR to terminate P12.

Upon a successful ignition, the Ascent Guidance takes over. During the entire APS burn, the crew monitors the VERB 06 NOUN 94 display, giving values of VGX, H-dot and H, as well as the FDAI readings, in order to identify PGNCS and engine performance and anticipate engine shutdown. The crew continues to monitor the VERB 06 NOUN 94 display noting that the x-component of VG in R1 is decreasing.

When a predetermined VGX or time to go has been reached, as indicated either by the NOUN 94 display of VGX or, optionally, by the NOUN 77 display of TG (which is the estimated time of flight from present time to ascent injection), the crew prepares for engine shutdown by first performing APS/RCS propellant interconnect and then putting the ENG ARM switch on the ENGINE THRUST CONT panel to OFF. Putting the ENG ARM switch to OFF removes the manual engine-on signal and enables automatic shutdown by P12. As stated above, the crew can either monitor the VERB 06 NOUN 94 display during ascent, or, optionally, key VERB 16 NOUN 77 ENTR into the DSKY to display TG, VGY (which is the y-component of the velocity-to-be-gained vector), and VI, and use the value of TG to monitor for shutdown. Upon finishing with the NOUN 77 display, the crew depresses the KEY REL pushbutton on the DSKY to return to NOUN 94.

Shutdown of the APS should occur when VGX, as seen in NOUN 94, is 20 to 60 fps (there is a 1 to 3 sec delay in this display); or TG, as seen in NOUN 77, is one to three sec. If automatic shutdown does not occur, the crew should depress the engine STOP pushbutton. After automatic shutdown, the crew records the values on the DSKY, which at shutdown changes to a flashing VERB 16 NOUN 94. (The crew keys VERB 34 ENTR in response to the flashing VERB 16 NOUN 94 display to terminate P12.) Nominally, the crew keys PRO to display VERB 16 NOUN 85 on the DSKY and examine the velocity residuals. To null out the v_G values, the crew sets the spacecraft PGNS switch to ATT HOLD and uses the attitude controller assembly (ACA) and the thrust translation controller assembly (TTCA) to null out VGX, VGY, VGZ. When satisfied with the residuals as seen in NOUN 85, the crew keys PRO or VERB 34 ENTR (terminate) into the DSKY to terminate P12. The crew can also call R30, the Orbital-parameters Display Routine, (by keying VERB 82 ENTR), and then re-establish the NOUN 85 display and terminate P12 as above.

3.3.1.6 Alarms

In addition to the normal output that can be expected from P12, alarms may occur requiring crew action. The crew can obtain a display of the alarm code by keying in VERB 05 NOUN 09 ENTR. The following is a list of alarms that may occur during P12 and a brief explanation of each:

a. Alarm 00220 occurs if the IMU is not aligned.
b. Alarm 00210 occurs if the IMU is not operating.
c. Alarm 01703 occurs if the t_{IG} is slipped during state vector integration.

d. Alarm 00401 occurs if the desired middle gimbal angle exceeds 70 degrees.

e. Alarm 00402 occurs if FINDCDUW is not controlling attitude.

> <u>NOTE</u>.—An alarm appears in both R1 and R3 of NOUN 09 if it is the only alarm; in both R2 and R3 if it is the second alarm; and only in R3 if it is the third alarm. R3 always contains the latest alarm. Further, R3 is not cleared by depression of RSET; R1 and R2 are so cleared.

If alarm code 00220 is displayed, the crew should depress RSET on the DSKY and align the IMU. If the IMU is already aligned, the crew must set the REFSMMAT flag.

Alarm code 00210 is unlikely to occur. Should it occur, however, indicating the IMU is not operating, the crew should depress RSET on the DSKY, turn on the IMU, wait 15 minutes, then perform a P57 alignment.

Should alarm code 01703 be displayed, indicating that the t_{IG} has been slipped during state-vector integration, the crew should depress RSET on the DSKY. If t_{IG} has been slipped appreciably, t_{IG} will be re-established after one CSM revolution. There is, however, a specified ignition total allowable time delay. This is the total time the thrusting maneuver may be delayed beyond the LGC-calculated t_{IG}. It is up to the crew to account for this time.

Alarm code 00401 is unlikely to occur, since it is displayed if the desired middle gimbal angle exceeds 70 degrees, warning the crew that continuing the maneuver might yield gimbal lock. Occurrence of this alarm probably indicates the the PGNCS is not functioning properly, and the crew should switch to AGS.

Alarm code 00402 is displayed if the FINDCDUW routine is not controlling attitude. The crew should either terminate thrust or go to the AGS as backup.

3.3.1.7 Restarts

P12 is restart protected. For most software restarts, the crew would observe illumination of the PROG alarm light, and the program going back to the last flashing display before the restart. Should a hardware restart occur, the RESTART light on the DSKY would be illuminated.

3.3.1.8 Primary Guidance (PGNCS) and Abort Guidance (AGS) Navigation Control Systems

If the Primary Guidance, Navigation and Control System should fail during P12, the crew can switch to the Abort Guidance System to take the LM to a safe orbit. The AGS calculates information in a manner analogous to the PGNCS and normally operates parallel to the PGNCS during descent and ascent. In this way, the AGS serves as a check on the PGNCS. While the LM is under AGS control, the PGNCS still operates. The crew can monitor the performance of the PGNCS by calling up PGNCS displays and comparing them with AGS displays. During a thrusting maneuver done under AGS control, the LGC continues computations of the position and velocity, desired thrust vector, and desired attitude errors, but the PGNCS is not responsible if any register overflows occur.

3.3.1.9 P12 Engine Shutdown

Engine shutdown involving the Ascent Propulsion System (APS) may occur during P12 for two reasons:

a. Shutdown occurring normally because target conditions have been achieved

b. Shutdown occurring prematurely because of a lack of thrust. Premature shutdown, noted by the Thrust Fail Routine, R40, is indicated to the crew by a flashing VERB 97 NOUN 94 display on the DSKY. (Refer to paragraph 3.3.1.4.1 for a description of R40 and responses to flashing VERB 97 NOUN 94.)

The crew can get an approximation to the time of P12 engine shutdown by observing VGX in the NOUN 94 display or by keying in VERB 16 NOUN 77 to get the estimated time of flight from present time to time of injection. (See Table 3.3.1-II.)

In the v_G display, R1, R2 and R3 contain the components of the velocity to be gained vector along the LM X, Y and Z axes, respectively (i.e., VGX, VGY, VGZ). When VGX reaches 200 ft/sec with engine on, the PGNCS system prepares for a controlled shutdown. As VGX approaches zero, the engine should shut off. If not, the crew depresses the engine STOP pushbutton.

Under normal conditions (i.e., target conditions have been achieved), following APS engine shutdown, the VGX residual should be trimmed by firing the RCS jets. Under premature shutdown conditions, if the APS cannot be restarted, the RCS jets are used to attain insertion (i.e., to achieve target conditions). In the latter case, however, the RCS jets may be used to attain insertion only if the APS fails less than 60 seconds before injection. Note that if insertion were obtained with a degraded PGNCS or AGS, a tweak burn would be performed within 2 minutes after insertion. Thrusting parameters Δv_x and t_{IG} are supplied by the ground 30 seconds after insertion. The PGNCS program, P47, would be used for this burn.

3.3.1.10 FDAI Displays

An important aspect of the P12 pre-ignition phase is the display to the crew of those FDAI readings associated with the early phases of the ascent maneuver. These displays, obtained by the VERB 06 NOUN 74 display (see the computational sequence), include (1) the yaw angle that should be present on the FDAI at the end of the vertical rise phase before pitchover, and (2) the FDAI pitch attitude after pitchover has been completed. A comparison of these displays with FDAI readings indicates to the crew whether or not the PGNCS guidance is functioning properly. If not, the crew can switch to the AGS as backup. For a detailed explanation of the vertical rise and pitchover maneuvers associated with Ascent Guidance, refer to subsection 3.3.

3.3.2 P70, Descent Propulsion System Abort—LGC

P70 (like P12 and P71) is basically an initialization program whose function is to supply targets for Ascent Guidance. (Refer to subsection 3.3.) P70 is used for Descent Propulsion System (DPS) aborts and can be called at any time from ignition at PDI until P68, the Landing Confirmation Program, is called. P70, however, should not be used during the last part of the landing maneuver and surface stay—up to the entry of P68—since the DPS fuel is almost depleted by then. (At least 1 minute of low DPS-thrust fuel should be left when this abort is called in order to attain 15 seconds of maximum DPS thrust.)

P70 serves to (1) set up guidance targets, and (2) initialize the engine parameters needed for the Ascent Guidance. These parameters are computed by taking into account the current mass at the time the abort is called.

During the powered landing maneuver programs (P63, P64, and P66), the Abort Discretes Monitor Routine (R11) checks both the ABORT (P70) and the ABORT STAGE (P71) pushbuttons to determine if either pushbutton has been depressed. (Refer to paragraph 3.3.3 for an explanation of P71, the APS abort.) If the ABORT pushbutton has been depressed, R11 calls up P70, terminating the landing programs. P70 is capable of controlling the abort maneuver to achieve an ascent orbit injection analogous to that achieved by P12. (Refer to paragraph 3.3.1.) P70 can also be called manually by keying VERB 37 ENTR 70 ENTR into the DSKY. Under normal circumstances, the method for calling P70 is determined by time limitations. If, however, the CHANBKUP switch has been set, the abort channel bit will be ignored by R11. In that case, P70 must be called using VERB 37.

Timing within an abort maneuver, itself, is variable, ranging from a few seconds using the RCS jets to nearly the full 7 min 15 sec of the nominal ascent. If the abort occurs early in PDI, Ascent Guidance will put the LM in a high apolune orbit that allows the CSM to catch up with the LM. If the abort occurs late in PDI, Ascent Guidance will put the LM in a low apolune orbit that allows the LM to catch up to the CSM. Figure 3.3.2-1 illustrates abort criteria. The figure should be used as a reference for answering general questions on aborting.

Primarily, P70 would control a non-PGNCS, non-DPS failure during the landing sequence if the abort occurred after PDI and before touchdown. Figure 3.3.2-2 illustrates the timeline for an abort during the landing sequence. Note that the LM Guidance Computer (LGC) does not automatically select the APS Abort Program (P71) if the DPS runs out of fuel. Therefore, the crew must anticipate fuel exhaustion

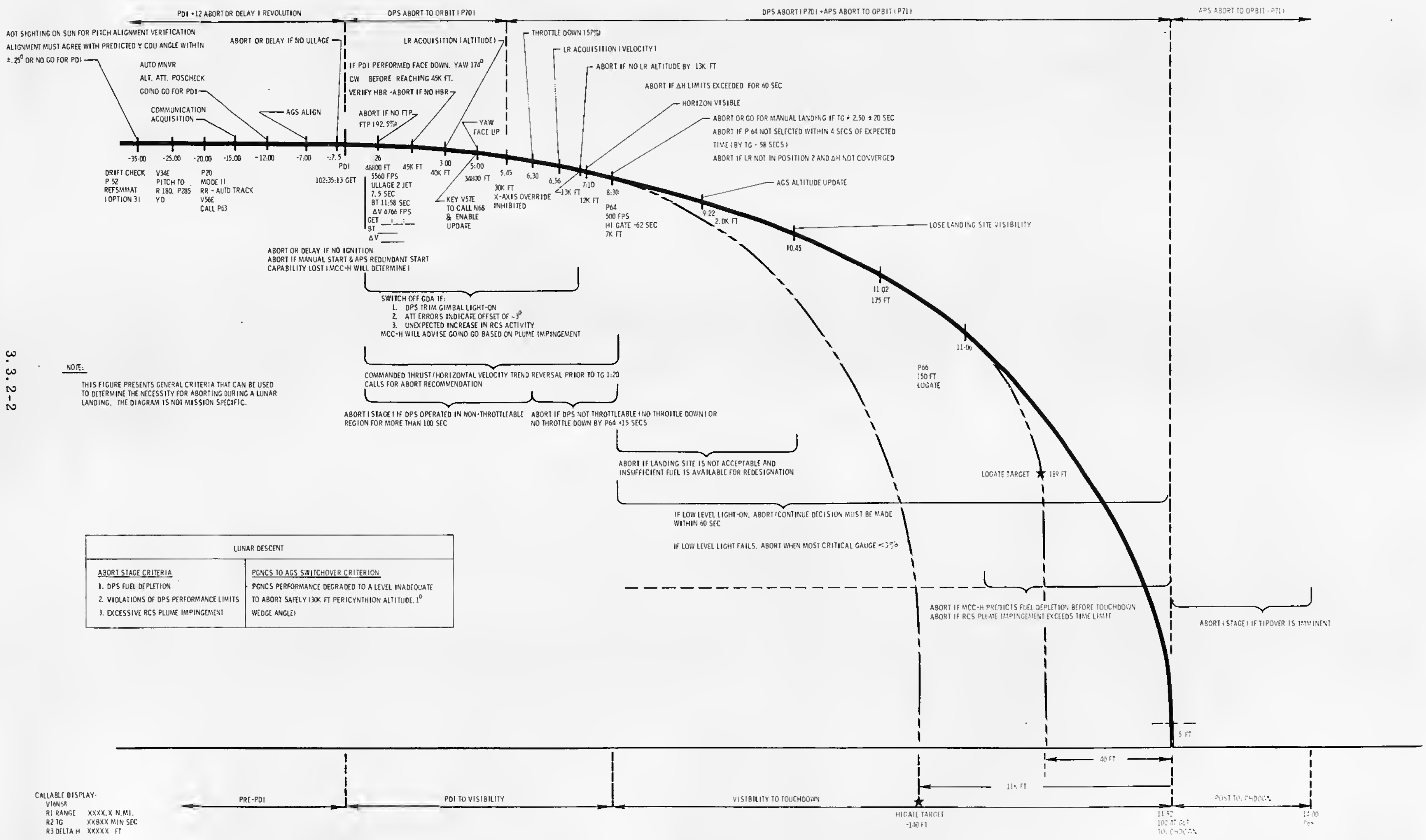

Figure 3.3.2-1. General Criteria to Determine Aborts During Lunar Landing

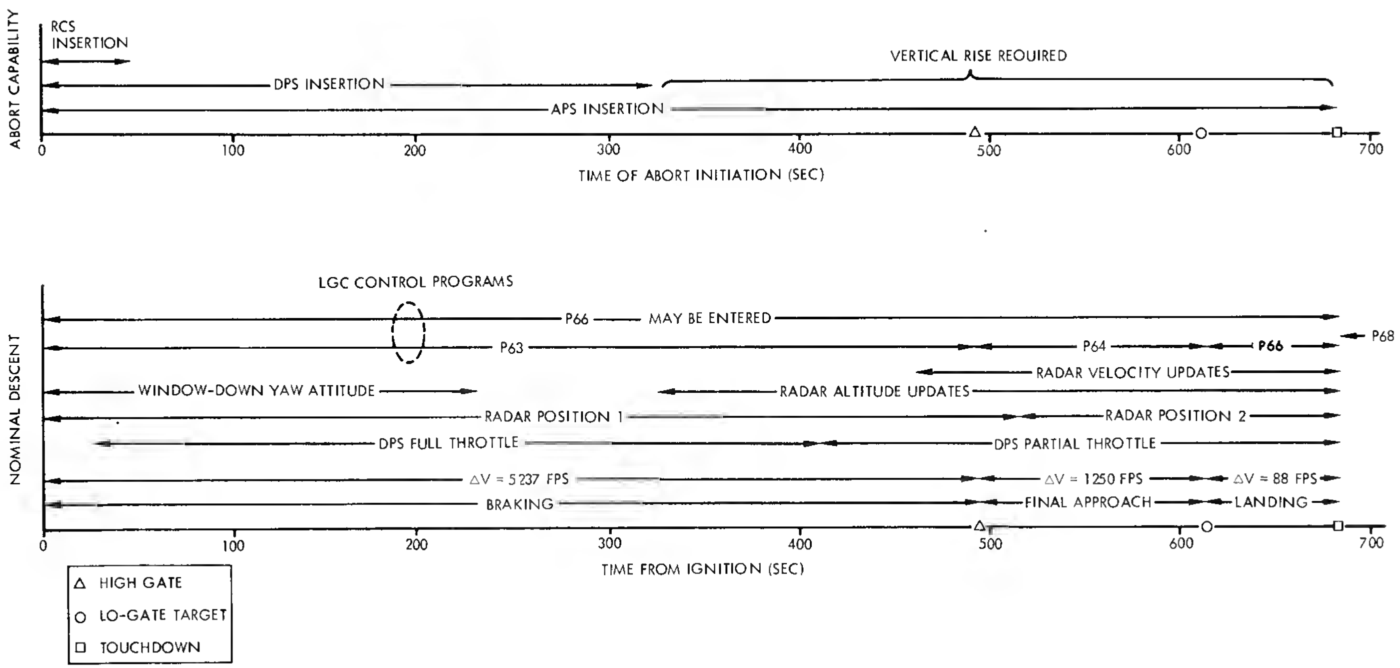

Figure 3.3.2-2. Powered Descent Timelines

and be prepared to select P71. P70 does, however, indicate engine cutoff and notifies the crew of this cutoff by a flashing VERB 97 when DPS fuel is depleted before orbit insertion is achieved. Refer to paragraph 3.3.2.2.3.

In an abort, an overshoot of 2.4 ft/sec downrange velocity could occur and is acceptable. After the burn, the crew can observe all three velocity residuals in NOUN 85, and null them out using the RCS jets. The decision to fire the RCS jets is based on the following:

a. The value of v_G remaining at DPS cutoff
b. Whether the DPS has been staged or not.

3.3.2.1 Abort Targeting

Abort targeting is an automatic process. Since aborts can happen at any time, no predetermined phasing is possible. (Refer to subsection 3.3 for a listing of targets provided during P12, P70 and P71.) A continuous targeting scheme has been developed, however, that attempts to provide an orbit that facilitates rendezvous. For APOLLO 11, ZDOTD was a cubic function of the time at which the abort had taken place. This calculation was done only once, however, during the initialization. The continuous targeting scheme was then developed for APOLLO 12. In this scheme, the major axis (i.e., the period of the orbit) of the targeted orbit is selected as a linear function of the current phase angle (θ) between the LM and the CSM. Then ZDOTD is computed from the major axis and the estimated insertion altitude. This computation is repeated every 2 sec during Ascent Guidance. As the LM approaches cutoff, the current phase angle approaches the phase angle for insertion.

During initialization, depending on the phase angle at abort, a choice is automatically made between two different linear functions of θ—one representing first-orbit rendezvous, the other, second-orbit rendezvous. The selection of the linear functions is final and is not re-examined during the burn. The crossrange value is restricted in magnitude to a pad-loaded value. During APOLLO 13, for example, the maximum allowable value was constrained to 0.5 deg or 8.2 n. mi.

3.3.2.2 Related Routines and Extended Verbs

The following is a list of routines associated with P70:

a. Landing Analog Displays Routine (R10)
b. Abort Discretes Monitor Routine (R11)

c. DPS/APS Thrust Fail Routine (R40)

d. AGS Initialization Routine (R47).

These routines are described in some detail below.

3.3.2.2.1 Landing Analog Displays Routine (R10).—Figure 3.3.2-3 is a flowchart of R10. R10 displays the following LGC-calculated parameters on the LM meters:

a. Inertial lateral velocity

b. Altitude—the present altitude of the LM above the lunar radius at the designated landing site

c. Altitude rate—present rate of change of altitude.

R10 calculates these display parameters and transmits them to the LM meters when the display inertial data discrete is available. This routine is automatically called every 0.25 second by the Abort Discretes Monitor Routine (R11). Note that R10 now uses the RR CDUs (forward and lateral velocity crosspointer) during P12, P70 and P71, although the Forward Crosspointer is always set to zero. The altitude and altitude rate is also displayed in P12, P70 and P71. R10 is terminated when AVERAGEG is terminated.

3.3.2.2.2 Abort Discretes Monitor Routine (R11).—Figure 3.3.2-4 is a flowchart of R11. R11 is used to monitor the abort and abort stage discretes to the LGC, which indicate whether the crew desires to abort from the powered landing maneuver. R11 selects the correct LGC program for the abort commanded by the crew—depending on whether the crew depresses the ABORT (P70) or the ABORT STAGE pushbutton (P71). In addition, R11 calls the Landing Analog Display Routine (R10). Refer to paragraph 3.3.2.2.1.

R11 is called every 0.25 second by the R10/R11/R12 Service Routine (R09), only when AVERAGEG is in progress, during P12, P63, P64, P66, P70 or P71.

3.3.2.2.3 DPS/APS Thrust Fail Routine (R40).—The Thrust Fail Routine (R40), automatically called by P70 every 2 seconds, monitors the IMU PIPA outputs for evidence of DPS thrust failure during the DPS abort. R40 initiates engine-fail procedures if the thrust monitor indicated a lack of engine thrust upon engine turn-on or during a thrusting maneuver. Refer to paragraph 3.3.1 for a flowchart of R40.

Initially, the thrusting program (i.e., P70) sets the Δv counter to 4. Consequently, R40 does not initiate engine-fail procedures after the nominal ignition time, unless

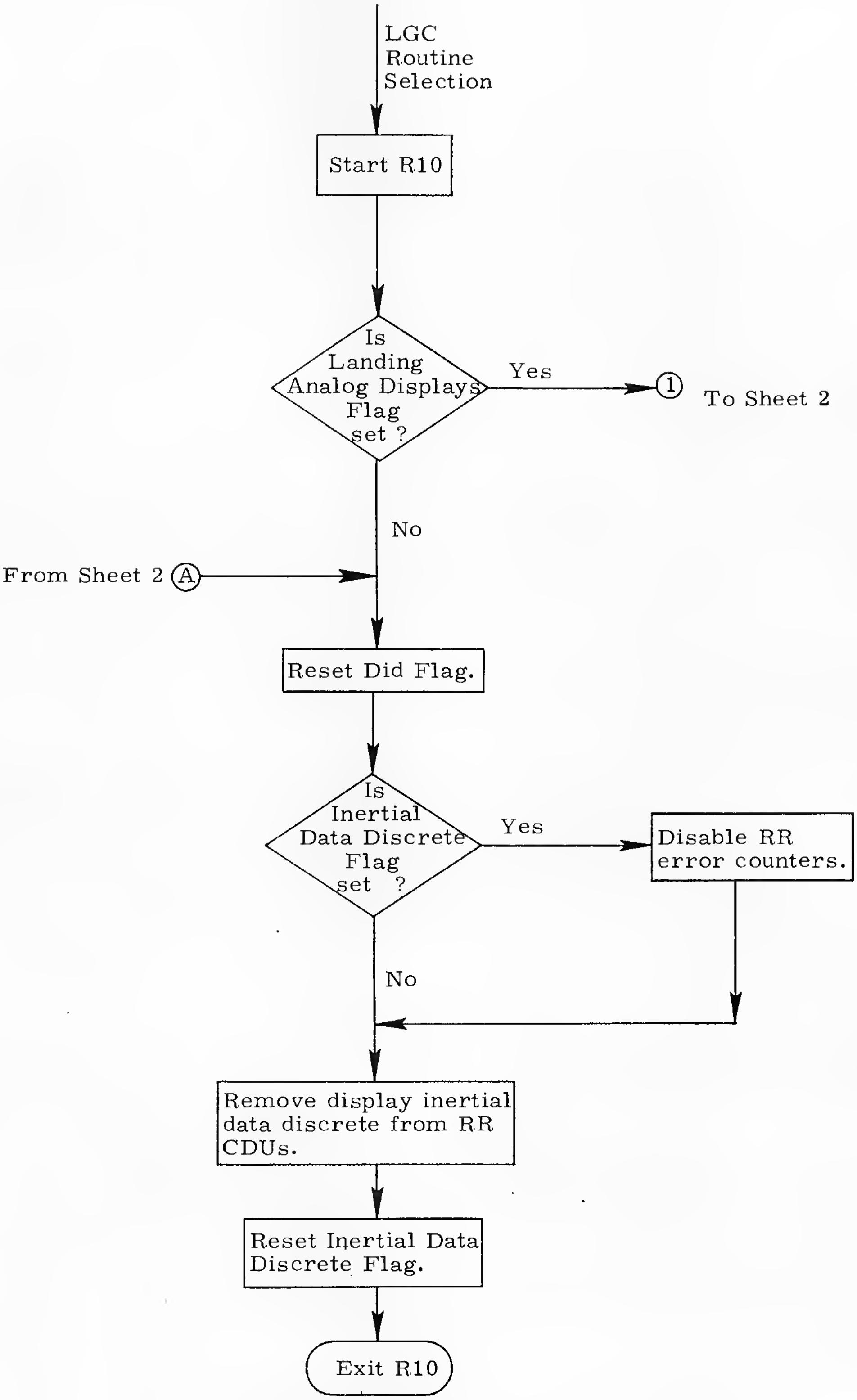

Figure 3.3.2-3. Landing Analog Displays Routine (LM R10) (Sheet 1 of 3)

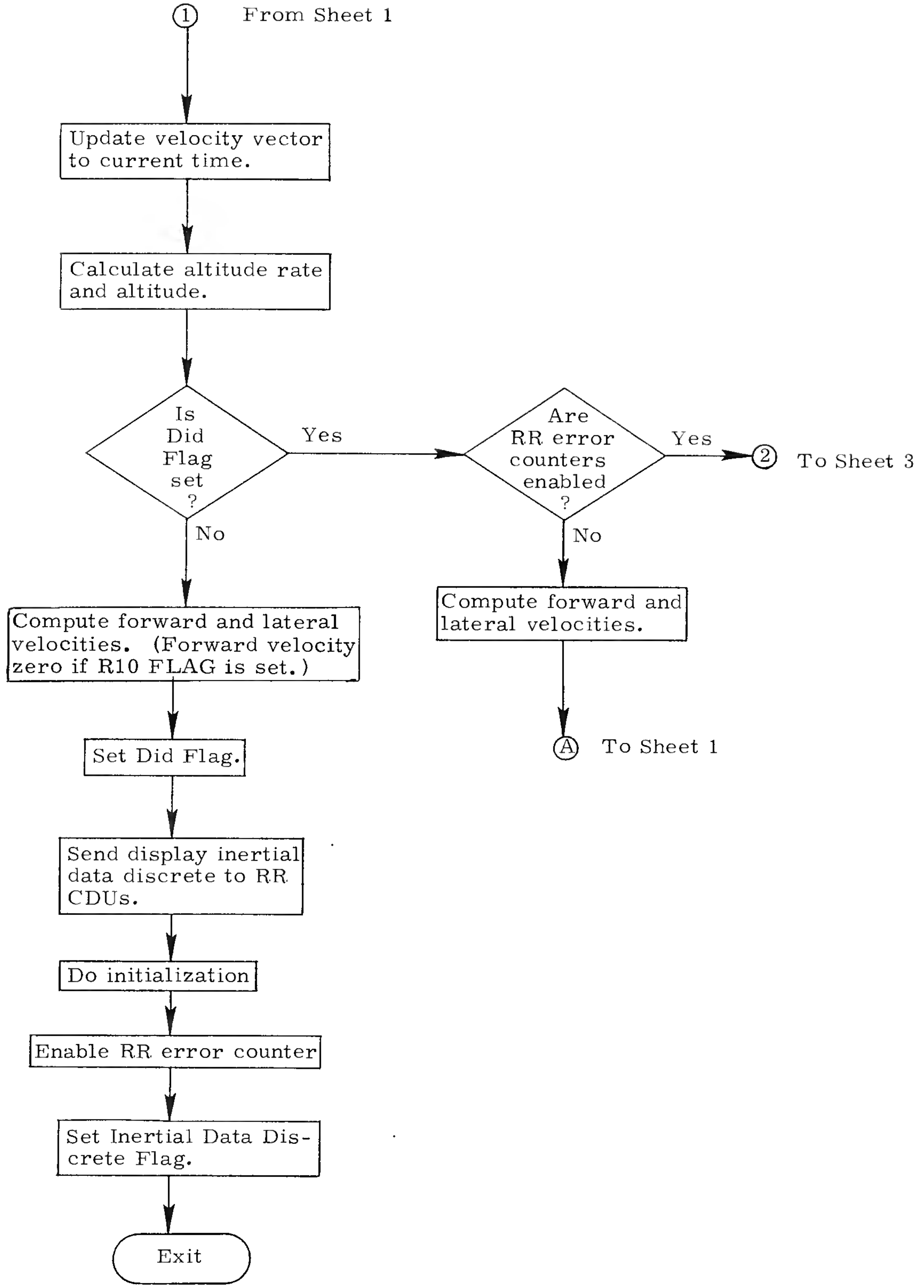

Figure 3.3.2-3. Landing Analog Displays Routine (LM R10) (Sheet 2 of 3)

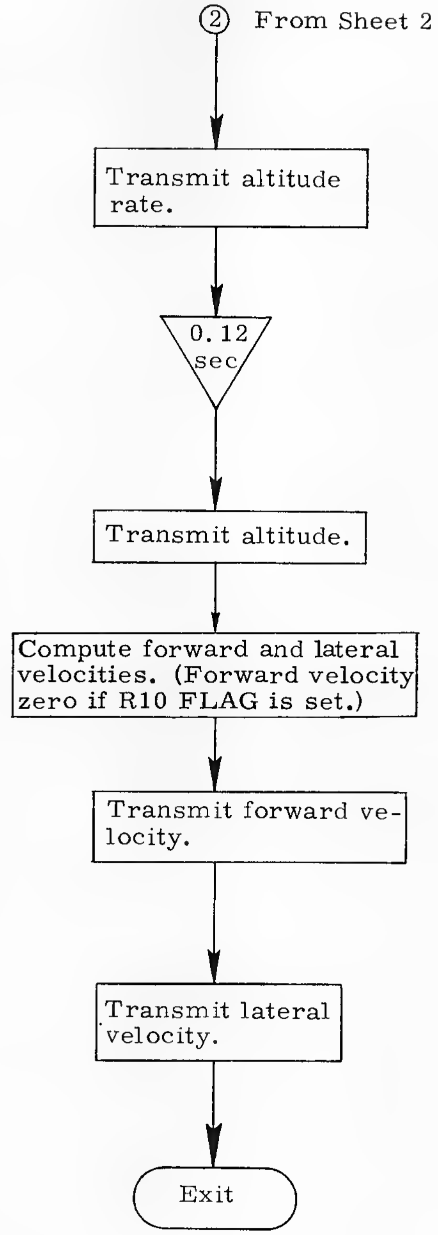

Figure 3.3.2-3. Landing Analog Displays Routine (LM R10) (Sheet 3 of 3)

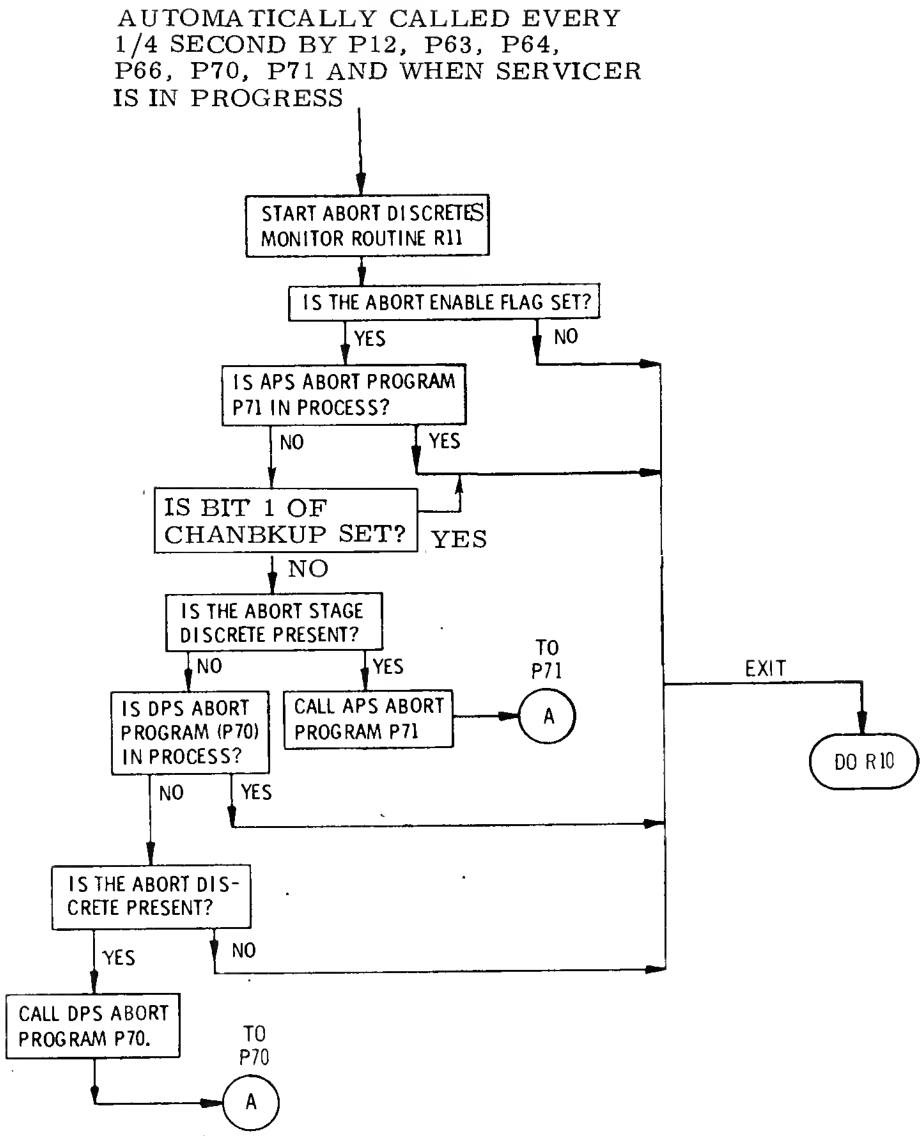

Figure 3.3.2-4. Abort Discretes Monitor Routine (LM R11)

acceleration is detected to be below 18 cm/sec^2 (a 2-sec velocity increment of 36 cm/sec) for 5 successive cycles of the Δv monitor. The threshold value for the Δv comparison is the same as that used by the landing guidance. If a satisfactory thrust level is sensed by the Δv monitor, the Δv counter is set to 1. Thus, once successful thrusting has started, only two successive low-thrust measurements are required to initiate the engine-fail sequence.

Engine thrust failure is indicated to the crew by a flashing VERB 97 NOUN 94 on the DSKY during the DPS Abort (P70). Before responding to this flashing VERB 97 display, the crew should verify that the thrust failure is indeed genuine. (See responses to the display, below.) The following are the responses to the VERB 97 NOUN 94 display in P70.

a. To verify the LGC interpretation of thrust failure, key PRO at the time the flashing VERB 97 display first appears. If the flashing display terminates, (the Δv counter is set to 4 by this action) and does not reappear within 12 sec, the failure was not genuine and P70 continues with the normal thrusting display restored. If the flashing display reappears, follow one of the procedures discussed below.

b. To terminate P70—without completing the DPS maneuver—key VERB 34 ENTR (terminate) into the DSKY.

c. To complete the DPS abort, key ENTR to the flashing VERB 97 display. The crew then has the following choices before continuing P70.

    1. To attempt completion of the DPS Abort maneuver using the RCS jets, key ENTR to the flashing VERB 97 display. Then, also key ENTR in response to the flashing VERB 99 display. (See paragraph 3.3.2.3.)

    2. To attempt a restart of the DPS in P70, first key ENTR to the flashing VERB 97 display, and then key PRO to the flashing VERB 99 display to continue the DPS Abort.*

    3. To terminate P70, key VERB 34 ENTR in response to the flashing VERB 99 display.

---

* The LGC will not perform throttle control (i.e., throttle will be set to minimum by the LGC). Ascent Guidance will not attempt to control the thrust vector until the thrust level exceeds a minimum value. Unless the crew advances the throttle soon after the attempted restart of the DPS, an overburn might result. Consequently, after restarting the DPS, any further DPS throttle control in P70 must be done by the crew.

3.3.2.2.4 AGS Initialization Routine (R47).—Figure 3.3.2-5 is a flowchart of R47. R47 is used to provide the AGS abort electronics assembly (AEA) with the LM and CSM state vectors in LM IMU coordinates. R47 does this by means of the LGC digital downlink. R47 zeros the ICDU, LGC and AEA gimbal angle counters (only when the IMU is on, but the IMUSE flag is not set), simultaneously establishing a common zero reference to measure the gimbal (Euler) angles. These angles define the LM attitude with respect to the IMU stable member. R47 establishes the ground elapsed time (GET) of the AEA clock as zero if the clock is initialized during this routine. (Flashing VERB 06 NOUN 16 is used to define the zero value for the clock in terms of GET. Refer to Figure 3.3.2-5.) R47 can be selected at anytime if no other extended verb, marking display or priority display is active. The crew selects R47 by keying VERB 47 ENTR into the DSKY after P70 is selected.

Table 3.3.2-I lists the extended verbs available during P70 and gives a brief explanation of each.

3.3.2.3 Computational Sequence

When P70 is called, the thrust magnitude filter is initialized. Because there is a decrease in vehicle mass during the descent burn before entry of P70, the vehicle dynamics must be related to the current mass. After the engine performance and thrust-filter initialization, the target conditions are set up for the abort. The desired cutoff conditions are then transferred from fixed to erasable storage so that the target conditions may be updated. Finally t_{go} is established as being:

$$t_{go} = t_{abort} - t_{IG}\ (PDI)$$

Table 3.3.2-II lists the displays associated with P70. Figure 3.3.2-6 illustrates the logical flow of P70. Reference should be made to the table and flowchart while reading the computational sequence detailed below.

The DPS Abort Program is called by depressing the ABORT pushbutton or by keying in VERB 37 ENTR 70 ENTR into the DSKY. If P70 is incorrectly selected for one of the following reasons, the OPR ERR light illuminates, informing the crew of the error:

a. P70 is already in progress.
b. The ABORT ENABLE flag is not set.*
c. The AVERAGEG flag is not set.

*P63 sets the ABORT ENABLE flag; P68 and P71 resets it.

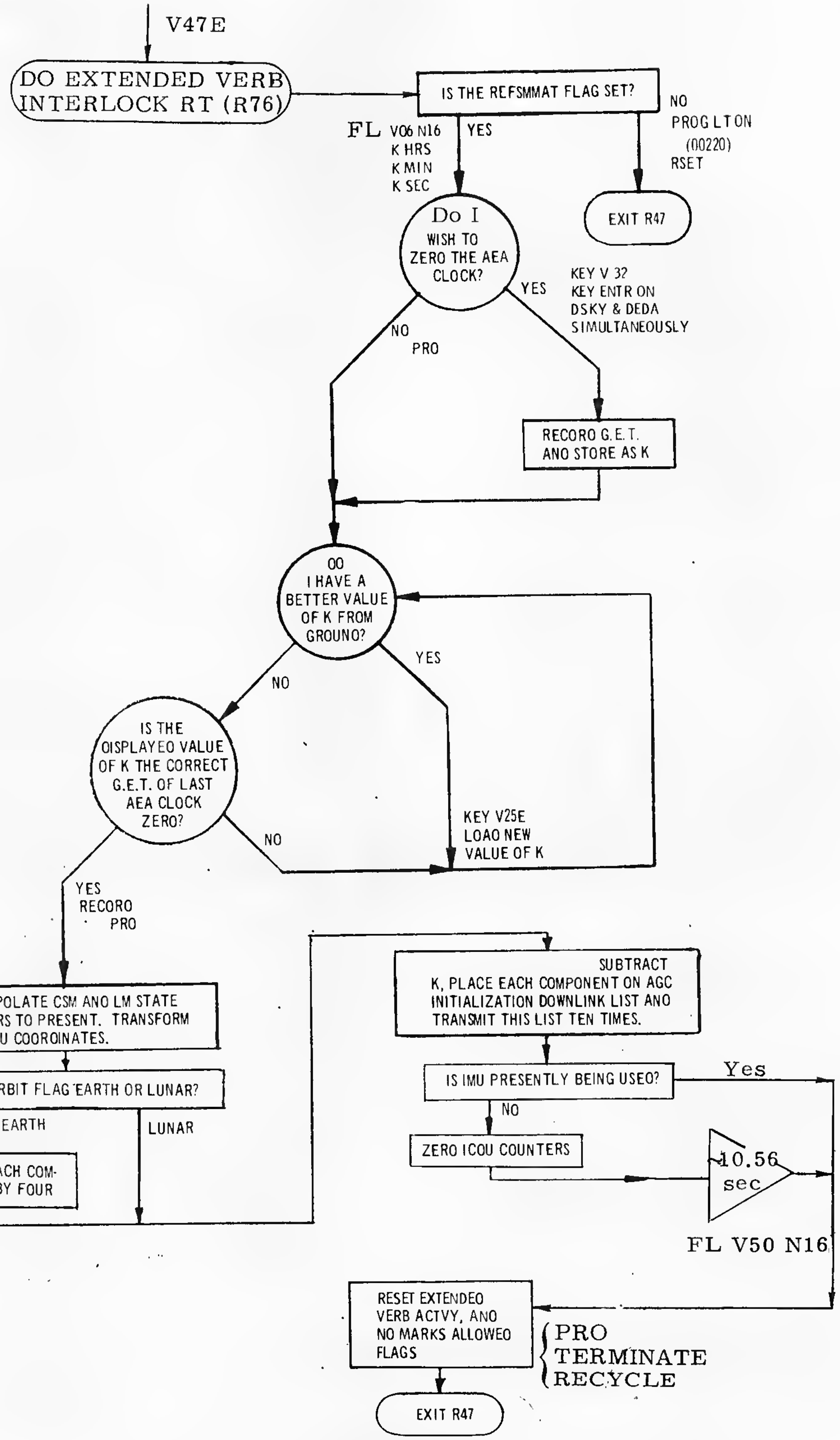

Figure 3.3.2-5. AGS Initialization Routine (LM R47)

TABLE 3.3.2-I

EXTENDED VERBS USED WITH DPS ABORT (LM P70) (SHEET 1 OF 3)

Verb	Identification	Purpose	Remarks
60 ENTR	Display PGNCS—derived vehicle attitude rates.	Display on the LM FDAI error needles the PGNCS—derived attitude rates.	This process may be selected any time during P70. Vehicle rates are available, however, only when the DAP is turned on.
61 ENTR	Display Mode I DAP attitude errors.	Display on the FDAI error needles the difference between the current CDU and the DAP command angles.	This process can be selected by the crew any time during P70. The crew can use Mode I error display to monitor the DAP's ability to track automatic steering commands.
62 ENTR	Display Mode II total attitude errors.	Display on the FDAI error needles the total attitude error—(NOUN 22) desired ICDU angles, minus (NOUN 20), present ICDU angles.	This process can be selected by the crew any time during P70. The crew can use Mode II error display to assist them in manually maneuvering the LM.
65 ENTR	Disable U, V jets during DPS burns.	Inhibits U and V (pitch-roll) RCS jet firings during DPS powered flight.	The crew can select Extended VERB 65 at any time in P70, but VERB 65 is intended mainly for P40 use.
75 ENTR	Enable U, V jets during DPS burns.	Enables U and V (pitch-roll) RCS jet firings during DPS powered flight.	Extended VERB 75 like Extended VERB 65 is mainly for P40 use, but is available to the crew in P70.
76 ENTR	Minimum Impulse Command Mode.	Enables the Minimum Impulse Mode of the DAP. The crew can then perform manual attitude control about all the vehicles axes with the ACA in the Minimum Impulse Mode.	Extended VERB 76 can be selected by the crew at any time. The crew must put the GUID CONT switch to PGNS and the MODE CONT switch to ATT HOLD.

TABLE 3.3.2-I

EXTENDED VERBS USED WITH DPS ABORT (LM P70) (SHEET 2 OF 3)

Verb	Identification	Purpose	Remarks
(76 cont)			The Minimum Impulse Mode will remain enabled until canceled by the rate command selection (Extended VERB 77) or a fresh start. It is strongly recommended that no powered flight maneuver be attempted in this Minimum Impulse Mode. The Minimum Impulse Mode is also canceled when P70 is first entered.
77 ENTR	Rate Command and Attitude Hold Mode.	Enables the Rate Command Mode of the DAP and sets the desired ICDU angles equal to the actual ICDU angles. The crew can then perform manual attitude maneuvers about all vehicle axes with the ACA in the Rate Command Mode.	Extended VERB 77 can be selected by the crew at any time. The Rate Command Mode will remain enabled until canceled by the Minimum Impulse Mode (see Extended VERB 76). The GUID CONT and MODE CONT switches should be set in the same way as in Extended VERB 76. Note that the Rate Command Mode is established at DPS ignition in P63 and when P70 is first entered.

TABLE 3.3.2-I

EXTENDED VERBS USED WITH DPS ABORT (LM P70) (SHEET 3 OF 3)

Verb	Identification	Purpose	Remarks
82 ENTR	Orbital Parameter Display Routine (R30).	Provides the crew with pertinent orbital parameters computed by the LGC, updated every 2 seconds during AVERAGEG, to supplement orbital information provided by the ground.	Extended VERB 82 is manually selected by the crew after the engine is shut down in P70, and the LM has achieved an orbit. If TFF is not computable (perilune altitude is greater than 35,000 ft) the LGC will set TFF equal to -59B59 compute TF PER and store it in NOUN 32, which the crew can call also.

TABLE 3.3.2-II

DPS ABORT DISPLAYS (LM P70) (SHEET 1 OF 3)

DSKY	Initiated by	Purpose	Condition	Register
FL V37	R00	Request Astronaut to select program (if ABORT push-button not used)	---	---
FL V50 N25	P70	Request desired modes for Guidance and attitude control for DPS abort be selected as follows: GUID CONT - PGNS ATT CONT - AUTO THROTTLE MODE - AUTO	ENTR - bypass request PRO - accept request by changing modes first	R1 00203_8 R2 Blank R3 Blank
V06 N94	P70	Display for monitoring DPS abort.	VGX–X-component of LM velocity-to-be-gained vector. HDOT–rate of altitude change H–altitude	R1 xxxx.x fps R2 xxxx.x fps R3 xxxxx ft
V05 N09 E	Astronaut (FINDCDUW routine)	Verify program alarm	00401 - desired middle gimbal angle exceeds 70 deg. 00402-FINDCDUW not controlling attitude.	* R1, R2, R3 $\}$ xxxxx
FL V16 N94	P70	Informs crew of DPS engine shutdown	Same as V06 N94	R1 xxxx.x fps R2 xxxx.x fps R3 xxxxx ft

* Refer to note in paragraph 3.3.1.6.

TABLE 3.3.2-II

DPS ABORT DISPLAYS (LM P70) (SHEET 2 OF 3)

DSKY	Initiated by	Purpose	Condition	Register
FL V16 N85 or V16 N85 E**	P70 or Astronaut	Monitor $\underline{v}_G$ components remaining during the DPS burn; after DPS shutdown monitor the $\underline{v}_G$ residuals during RCS trimming	VGX–X-component of $\underline{v}_G$ VGY–Y-component of $\underline{v}_G$ VGZ–Z-component of $\underline{v}_G$	R1 xxxx.x fps R2 xxxx.x fps R3 xxxx.x fps
V06 N76 E	Astronaut	Display targeting information	ZDOTD–downrange velocity RDOTD–radial velocity Crossrange	R1 xxxx.x fps R2 xxxx.x fps R3 xxxx.x n. mi.
V16 N77 E	Astronaut	Display additional components to be used in monitoring DPS engine shutdown	TG–estimated time of flight from present to injection (-polarity). VGY–Y-component of $\underline{v}_G$ VI–magnitude of LM inertial velocity	R1 xxBxx min, sec R2 xxxx.x fps R3 xxxx.x fps
V 82 E†	Astronaut	To call R30 the orbital parameter display routine	---	---
FL V16 N44	R30	Displays orbital parameter information to supplement ground information	Apolune altitude of LM orbit Perilune altitude of LM orbit Time of free fall to 35,000 ft.	R1 xxxx.x n. mi. R2 xxxx.x n. mi. R3 xxBxx min, sec

** V16 N85 can be keyed in anytime during the DPS abort.

† VERB 82 can be keyed in after DPS shutdown (i.e. FL V16 N94)

TABLE 3.3.2-II

DPS ABORT DISPLAYS (LM P70) (SHEET 3 OF 3)

DSKY	Initiated by	Purpose	Condition	Register
(FL) V06 N32 E†† or (FL) V16 N32 E	Astronaut	Display time from perilune†††	TF perilune	R1 ooxxx hrs R2 oooxx mins R3 oxx. xx sec

†† NOUN 32 display flashes if keyed in over a flashing display. V16 or V06 can be used to call the NOUN 32 display.

††† If TFF is not computable, i.e., perilune exceeds 35,000 ft., the LGC sets TFF to -59B59 and computes TF perilune storing it in the NOUN 32 display

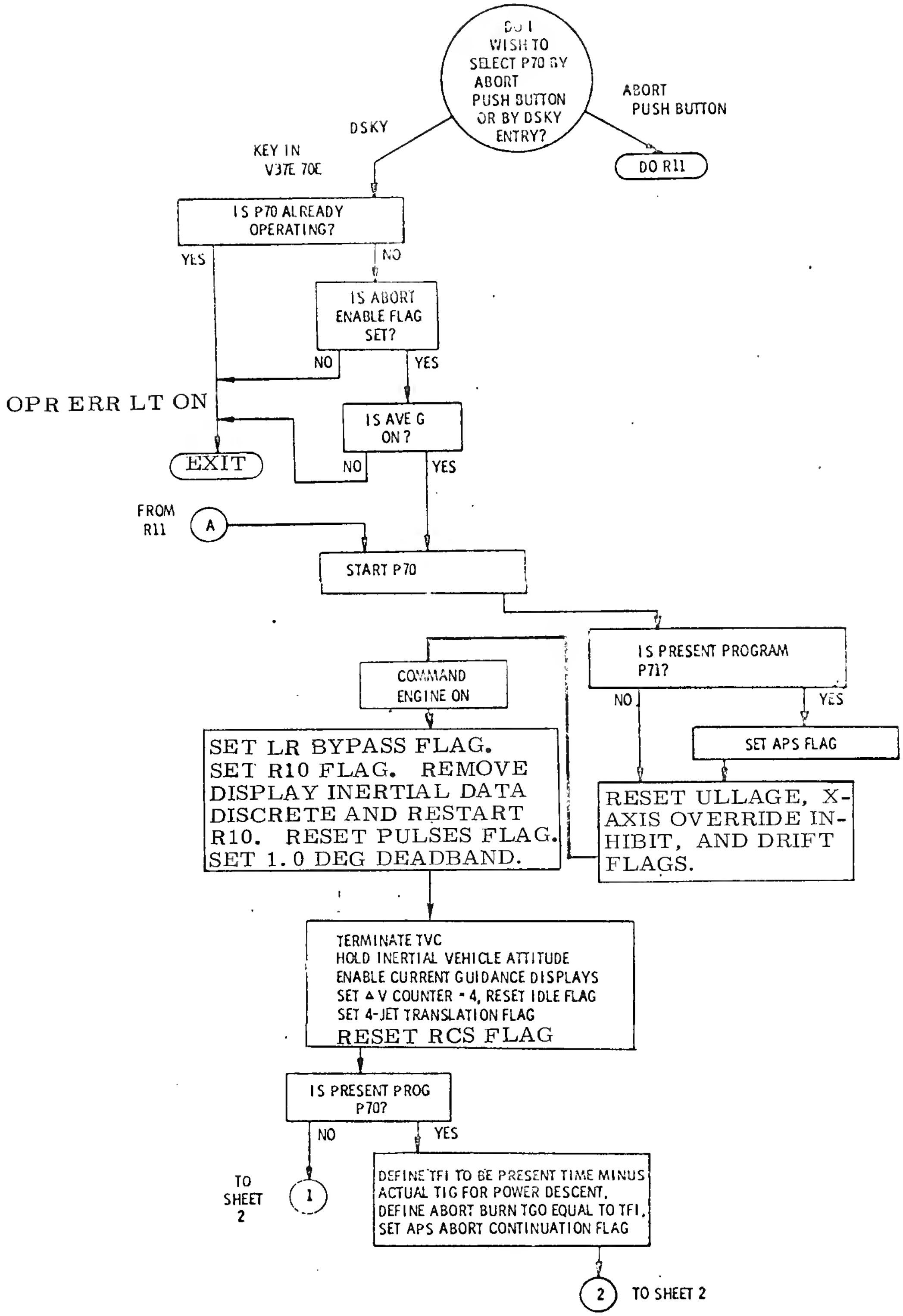

Figure 3.3.2-6. Descent Propulsion System Abort (LM P70) (Sheet 1 of 6)

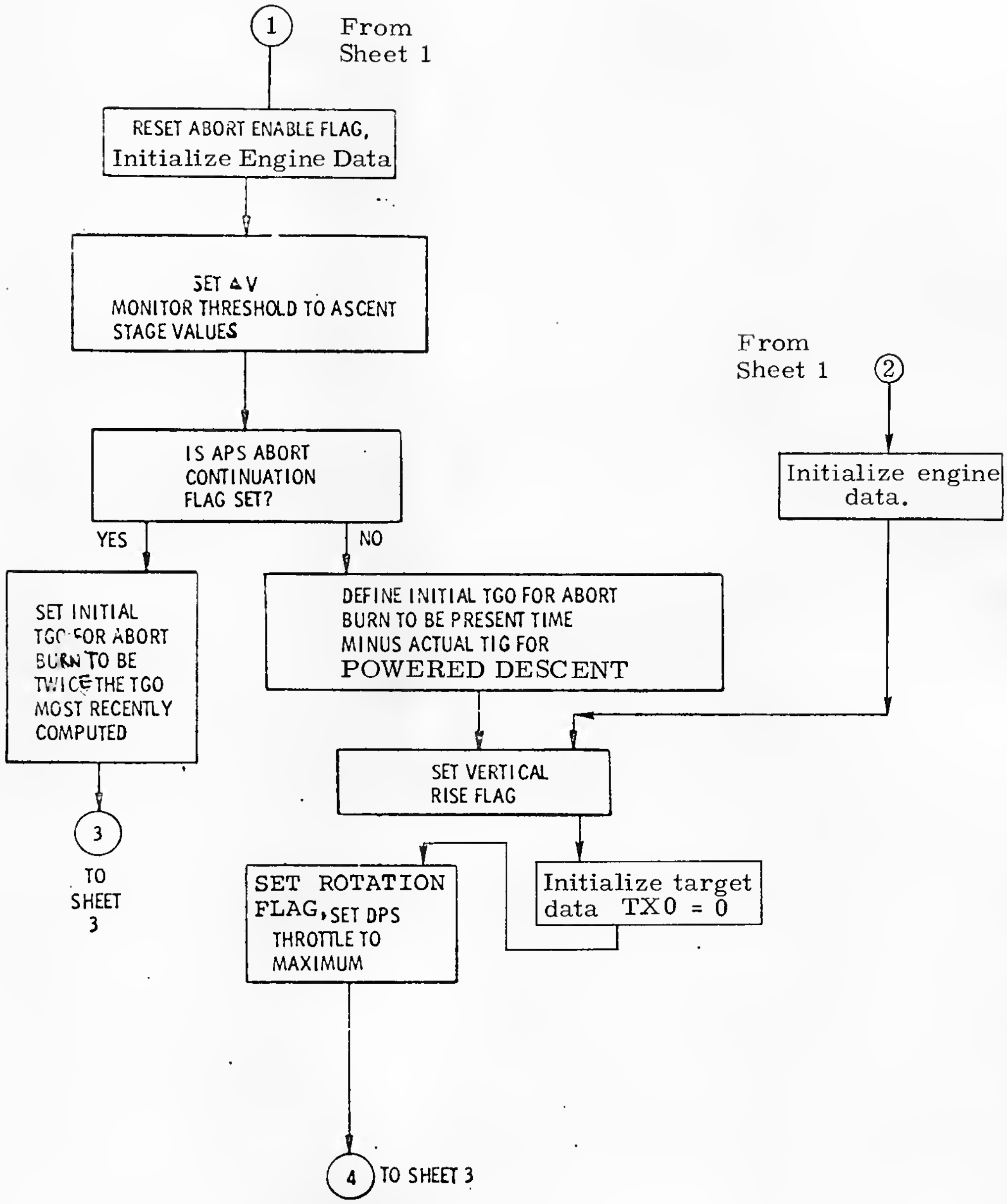

Figure 3.3.2-6. Descent Propulsion System Abort (LM P70) (Sheet 2 of 6)

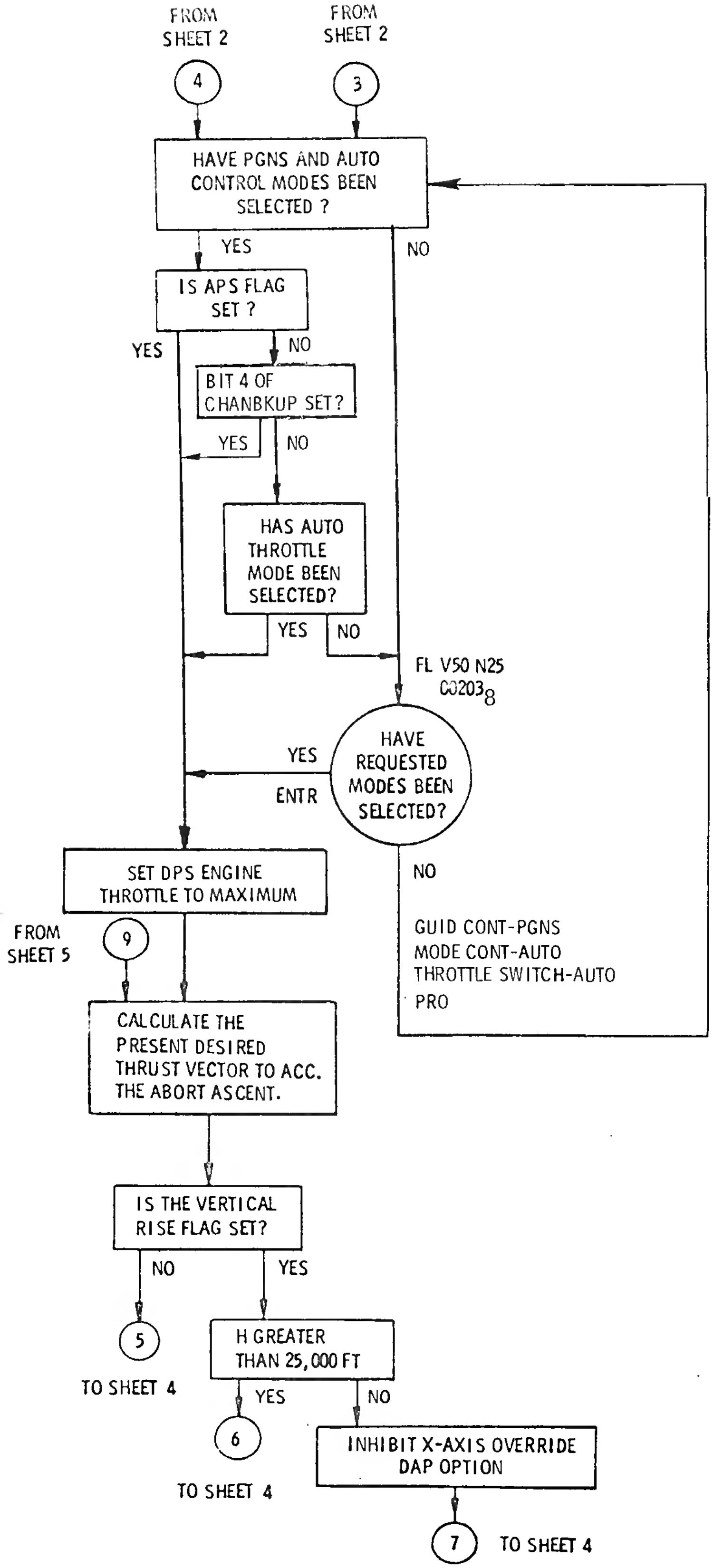

Figure 3.3.2-6. Descent Propulsion System Abort (LM P70)
(Sheet 3 of 6)

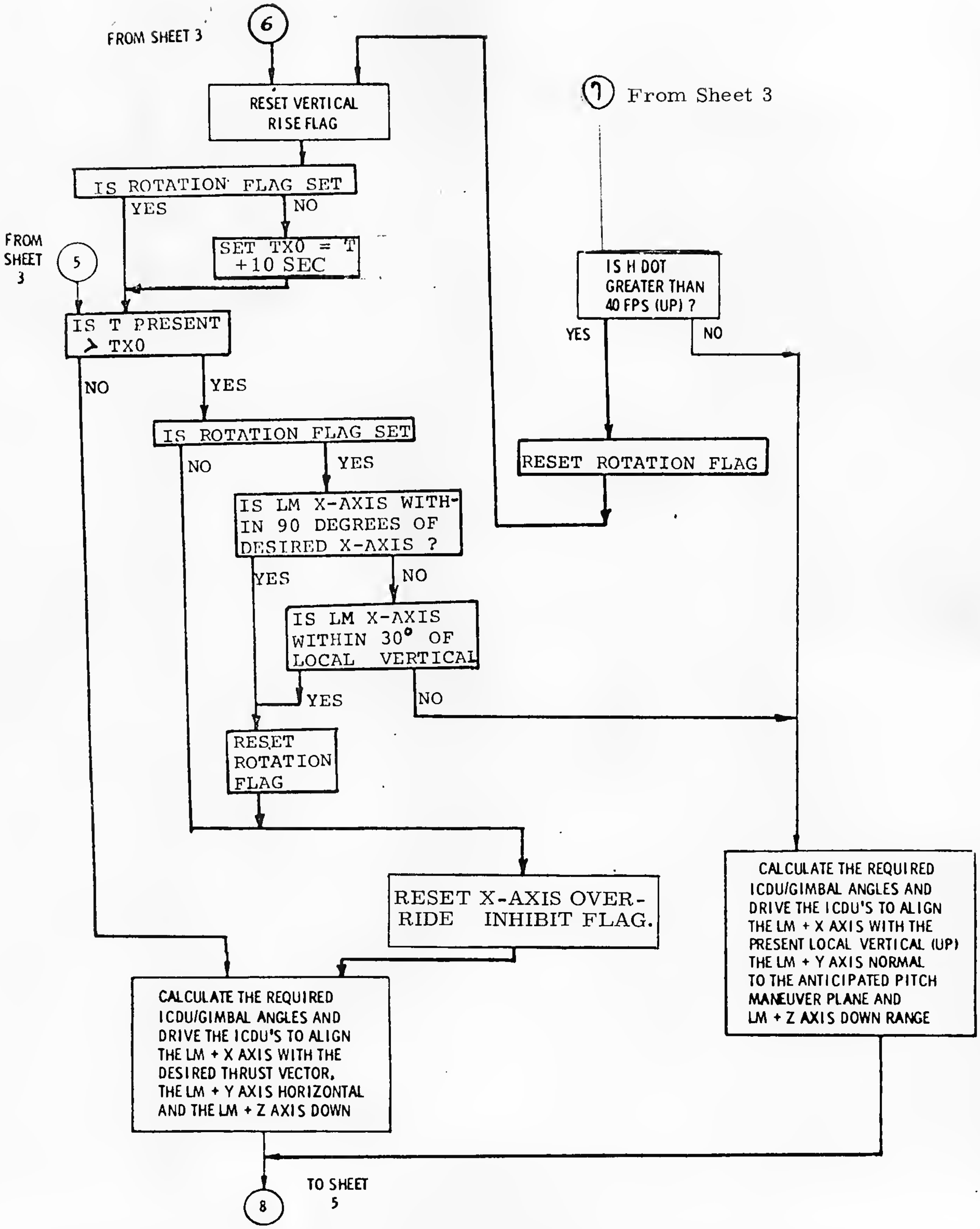

Figure 3.3.2-6. Descent Propulsion System Abort (LM P70) (Sheet 4 of 6)

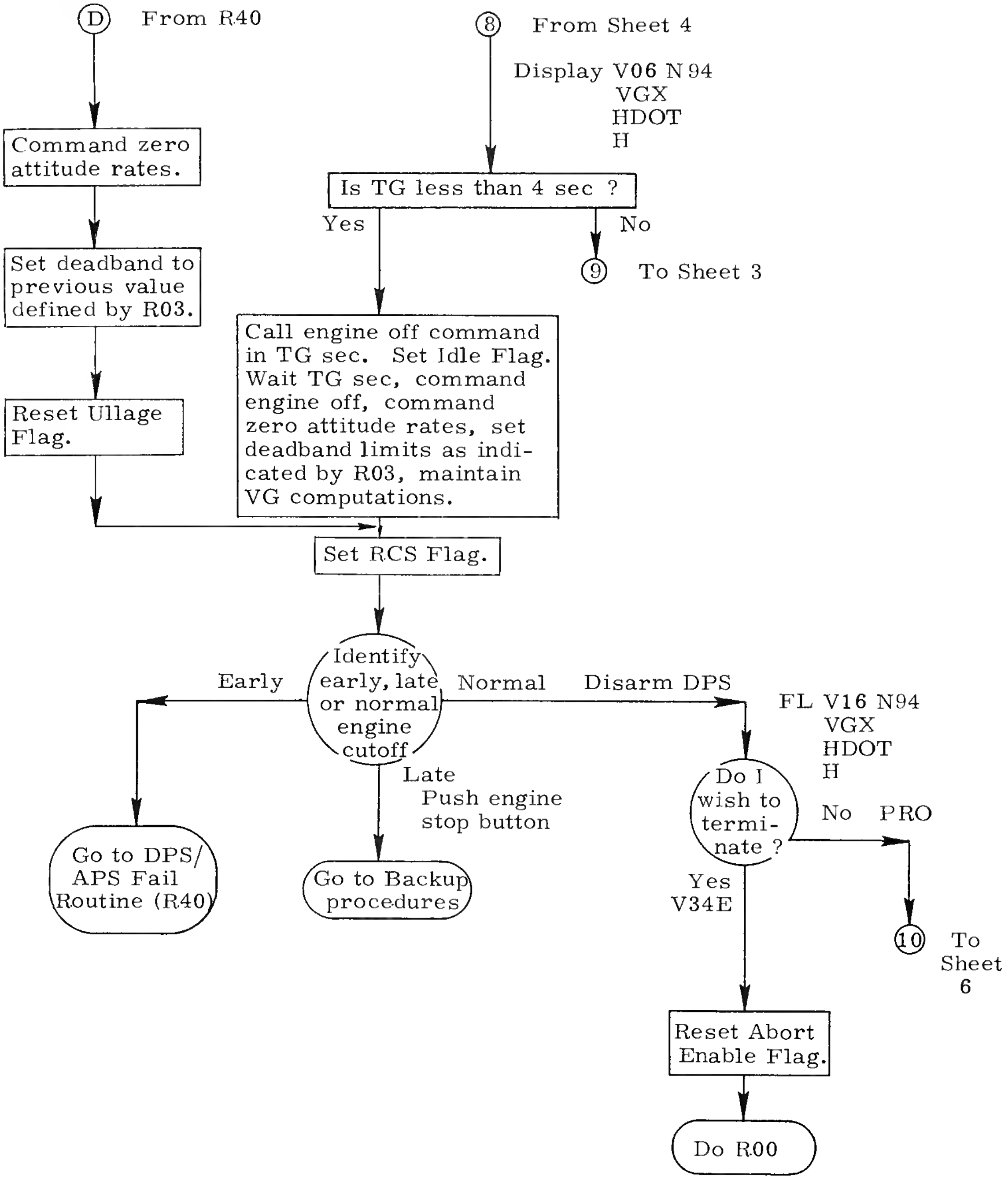

Figure 3. 3. 2-6. Descent Propulsion System Abort (LM P70) (Sheet 5 of 6)

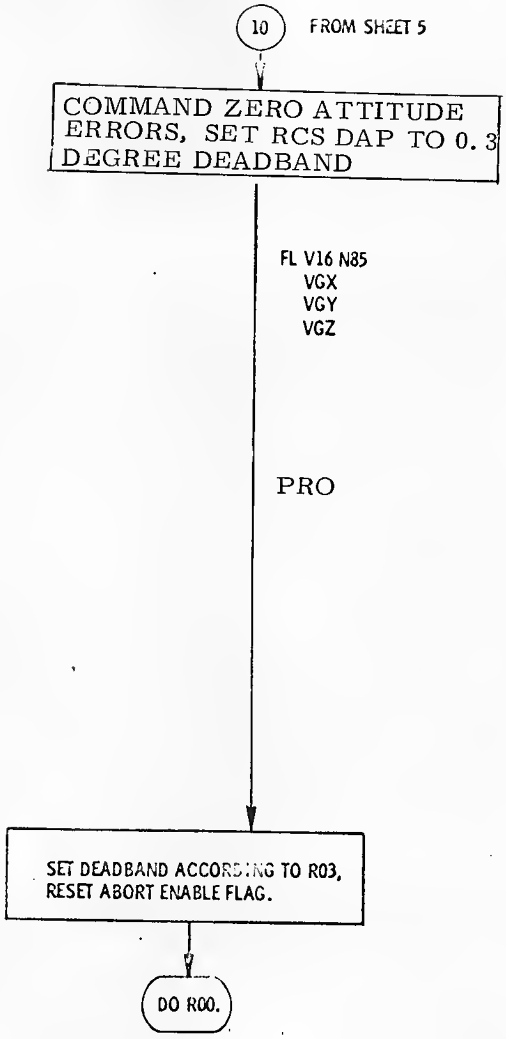

Figure 3.3.2-6. Descent Propulsion System Abort (LM P70) (Sheet 6 of 6)

Otherwise, P70 is displayed on the DSKY indicating that the DPS Abort Program has started. After a few flags are appropriately set, the DPS engine is commanded on by P70. Note that if a total thrust failure has occurred, the crew must apply manual RCS translation until P70 automatically commands the DPS engine on.

Since the crew—before selecting the abort—was in the process of landing thc LM, the LGC now removes the inertial data discrete from the CDUs and restarts R10, the Landing Analog Display Routine. In addition, the LGC also controls the following processes:

a. Sets 1.0 degree deadband.
b. Terminates thrust vector control.
c. Holds inertial vehicle attitude.
d. Sets the Δv counter to 4 for use by R40, the Thrust Fail Routine.
e. Enables the current guidance displays.
f. Resets the IDLE and RCS flags.
g. Sets the 4-jet translation flag.

Then the LGC calculates the initial t_{go} for the abort burn and sets a flag to allow P71, the APS Abort, to be set up properly as a follow-up to P70. (Note that if P71, is called as a follow-up to P70, the value of t_{go} will be twice that of the t_{go} that P70 has most recently computed.) The initial target conditions for the abort are then set up. See paragraph 3.3.2.1 for a description of the abort targets.

During the time that the above calculations are being performed by the LGC, the crew can set the GUID CONT switch to PGNS, the THR CONT switch on the ENGINE THRUST CONT panel to AUTO and the PGNS MODE CONTROL switch to AUTO. By monitoring the thrust indicator on the MAIN PROPULSION panel, the crew can observe that the DPS comes to full thrust, since P70 has set the DPS engine throttle to the maximum value. If the crew has not selected the modes (as described above), a flashing VERB 50 NOUN 25 with R1 set to 00203 appears on the DSKY requesting that the crew "please perform" selection of these modes. To ignore the request, the crew keys ENTR. To comply with the request, the crew changes the modes, and keys PRO. Once again, the DPS engine throttle is set to maximum and, again, the crew should observe the maximum thrust, as described above.

> NOTE.—Bit 4 of CHANBKUP can be used to override the setting of the THR CONT switch as a protection against channel failures. CHANBKUP is displayed in R2 of NOUN 46, and can be loaded via VERB 22 NOUN 46 ENTR, taking care not to disturb other bits. The effect of having this bit set is that the THR CONT switch position will not affect the decision to display VERB 50 NOUN 25.

The LGC then calculates the present desired thrust vector to accomplish the abort ascent conditions and determines if a vertical rise and pitchover maneuver is required. (An explanation of vertical rise and pitchover can be found in subsection 3.3.)

Regardless of whether the LM enters the vertical rise and pitchover phases or not, the LGC next calculates the required ICDU/gimbal angles and drives the ICDUs to align the LM +X-axis appropriately.

During the abort maneuver, the crew monitors the DSKY, FDAI, and looks out the window. During the entire DPS burn, the DSKY displays VERB 06 NOUN 94 containing values of the x-component of the velocity-to-be-gained vector, the rate of altitude change, and the present altitude. When the abort is called, if the altitude is greater than 25,000 ft on the first pass through the guidance, the X-axis-override option is not inhibited for the remainder of the ascent. If the altitude is less than 25,000 ft on the first pass, however, the X-axis-override option is inhibited. In this case, the option can become available on subsequent passes through the guidance under either of the following conditions:

a. If the radial rate exceeds 40 fps (up) before the altitude exceeds 25,000 ft, a timer is set to permit X-axis-override in 12 sec.
b. If the altitude exceeds 25,000 ft before the radial rate exceeds 40 fps (up), the option remains inhibited until either the 30- or the 90-deg rotational test is passed. The override option then becomes available immediately.

When either of these conditions is satisfied, the PGNCS pitches the LM to the correct attitude to perform the ascent abort and once again restores the X-axis-override option. The above maneuvers will be done with the RCS jets while the DPS is at full thrust.

While monitoring the DSKY, the crew should also be observing the FDAI attitude errors and attitude rates, as well as monitoring the thrust indicator for the DPS. The crew should then prepare for DPS engine shutdown, identifying early, late, or normal cutoff. If the target conditions are not met, and the DPS is shut down early, the crew sees a flashing VERB 97 display from R40 on the DSKY indicating thrust failure. By responding appropriately to this flashing VERB 97 display (see paragraph 3.3.2.2.3), the crew returns to P70 to attempt to re-ignite the DPS, complete the abort ascent using the RCS jets, or call the APS Abort Program (P71). Note that it is very likely that the DPS will run out of fuel in a long abort ascent. The crew

determines engine shutdown by monitoring R1 of NOUN 94 (displaying VGX), or, optionally, by keying in VERB 16 NOUN 77 to monitor TG. When the DPS is shut down, the display changes to a flashing VERB 16 NOUN 94.* In response to this flashing display, the crew disarms the DPS and, if desired, keys PRO to get a display of flashing VERB 16 NOUN 85, the velocity residuals, VGX, VGY, VGZ—possibly nulling them out by an RCS trimming maneuver. (NOUN 85 can be called at anytime during the abort maneuver. See paragraph 3.3.2.6 on use of RCS jets during P70/P71 aborts.) Alternatively, the crew can key VERB 34 ENTR (terminate) into the DSKY to end P70, or key VERB 82 ENTR to call R30, the Orbital-parameters Display Routine, to monitor continuous updated values of apolune, perilune, and TFF. The crew can also terminate P70 by keying PRO or VERB 34 ENTR in response to the flashing VERB 16 NOUN 85 display when satisfied with the velocity residuals.

3.3.2.4 Alarms

In addition to the normal output expected from P70, alarms may occur calling for crew action. The crew can get a display of the alarm code by keying in VERB 05 NOUN 09 ENTR. (Refer also to the note in paragraph 3.3.1.6 for the order of appearance of alarms on the DSKY.) The following are alarms that may occur during P70:

a. A 00401 alarm may occur as a warning to the crew of impending gimbal lock.
b. A 00402 alarm may occur if FINDCDUW is not controlling attitude.

If alarm code 00401 is displayed, it indicates that the desired gimbal angle exceeds 70 degrees. Continuing the maneuver might result in gimbal lock. This alarm is unlikely to occur. Should it occur, however, it probably indicates that the PGNCS is not functioning properly; the crew should switch to AGS.

Alarm code 00402 is displayed if the FINDCDUW routine is not controlling attitude. The crew should either terminate thrust, or go to the Abort Guidance System (AGS) as backup. Refer to paragraph 3.3.1.8 for an explanation of the relation between the PGNCS and the AGS.

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* Note that if engine shutdown is identified as being later than desired, the crew should depress the engine STOP pushbutton.

3.3.2.5 Restarts

P70 is restart protected. For most software restarts, the crew observes the illumination of the PROG alarm light; the program also goes back to the last flashing display before the restart. Should a hardware restart occur, the RESTART light on the DSKY illuminates.

3.3.2.6 Engine Cutoff During Aborts

If P70 is called after t_{IG} + 300 sec, it is very likely that the DPS fuel will be depleted before insertion is accomplished. The crew must be aware of the v_G values at engine shutdown to be able to achieve target conditions. Based on the value of v_G, a decision must be made concerning overburn and minimum APS burntime constraints. The crew can get the v_G display by keying VERB 16 NOUN 85 ENTR into the DSKY. The registers R1, R2 and R3 contain the components of v_G, VGX, VGY and VGZ, respectively.

When v_G is greater than 30 ft/sec, at DPS engine shutdown, the ABORT STAGE pushbutton must be depressed to call P71, the APS Abort Program, to accomplish insertion. As a result of the 2-second Ascent Guidance cycle, the minimum allowable APS burn is set at 3 seconds to avoid propellant freezing in the engine. The v_G in this 3-second APS burn is approximately 30 ft/sec, which is the overburn boundary value. (Refer to Figure 3.3.2-4.) If the value of v_G is less than 30 ft/sec at DPS shutdown, the RCS jets must be used to accomplish insertion since a large overburn will occur if the APS engine is used.

If an overburn occurs, the display would show v_G increasing after a decrease to some minimum value. If the DPS continues to thrust as v_G goes negative, the engine should be shut down by manual action. There is, however, a 2- to 4-second delay in the computation of v_G before it is displayed to the crew. Thus, before making the decision as to whether the LM is in an overburn or not, the crew must wait for the display to stabilize. Overburns with the DPS or APS are trimmed by RCS thrusting in a negative direction.

Before stabilization of the v_G display, if VGX is over 100 ft/sec, the ABORT STAGE pushbutton should be depressed. After stabilization of the v_G display (a delay of 6 seconds should be adequate), the crew is left with one of the three following choices:

a. If VGX is greater than 30 ft/sec, depress the ABORT STAGE pushbutton.

b. If VGX is less than 30 ft/sec, but greater than 5 ft/sec, manually stage the DPS and fire the RCS jets.

c. If VGX is less than, or equal to, 5 ft/sec, fire the RCS jets with the DPS attached. Note that the RCS jets should only be fired for approximately 15 seconds with the DPS attached. Firing for longer than 15 seconds causes damage to the DPS, and reflects on the APS stage structure.

BLANK

3.3.3 P71, Ascent Propulsion System Abort—LGC

P71, the Ascent Propulsion System (APS) Abort Program is an initialization program whose function is (1) to supply the targets for Ascent Guidance, and (2) to initialize the "engine parameters" needed by Ascent Guidance.* For P71 (as opposed to P70) these "engine parameters" are pre-loaded in the LM Guidance Computer (LGC). Note that when P71 is called after P70, no targeting initialization is done, since P70 has continuously updated the targets for the Ascent Guidance.

P71 is used for APS aborts and can be called at any time from ignition at PDI until P68, the Landing Confirmation Program, is called. (For an explanation of timing for aborts, abort criteria, and specific questions on aborting, refer to paragraph 3.3.2.) During the last part of the landing maneuver and surface stay—up to the entry of P68—the APS abort must be used since the DPS fuel is almost depleted.

The APS abort is called either by depressing the ABORT STAGE pushbutton or by keying VERB 37 ENTR 71 ENTR into the DSKY.

> NOTE.—Bit 1 of CHANBKUP can be used as an override for the abort stage input channel, to protect against a channel failure. If the bit has been set, the abort stage channel will be ignored by R11, and VERB 37 ENTR 71 ENTR must be used to call P71.

The program is called when any of the following conditions arise:

a. The DPS engine fails during the landing sequence.
b. The DPS runs out of fuel or fails during a DPS abort maneuver (i.e., during P70).
c. A lunar surface abort is to be performed before P68 has been called.

During an abort, if the DPS engine is cut off before orbit insertion, the crew is notified of the cutoff by a flashing VERB 97 display. (Refer to paragraph 3.3.3.1.1.) The crew can use the normal ascent display, NOUN 94, to monitor VGX, or optionally call VERB 16 NOUN 85 to monitor all three components of v_G during the DPS burn. The following three decisions are based on v_G values at engine cutoff time:

a. Fire the RCS jets (with the DPS attached).
b. Manually stage the DPS and then fire the RCS jets.
c. Depress the ABORT STAGE pushbutton to call P71.

* Refer to subsection 3.3 for a complete description of the Ascent Guidance.

Refer to paragraph 3.3.2.6 for further information on engine cutoff during aborts.

If the DPS runs out of fuel during P70, the LGC does not automatically select the APS Abort. The crew must, therefore, anticipate fuel exhaustion and be prepared to select P71 either by keying VERB 37 ENTR 71 ENTR into the DSKY, or by depressing the ABORT STAGE pushbutton.

If a lunar surface abort is to be performed, the ABORT STAGE pushbutton is depressed before P68 has been called. A typical flight plan associated with the lunar surface abort is given below:

EVENT	TIME FROM IGNITION (PDI IGNITION)
Touchdown	690–775 sec
STAY/NO-STAY for lunar surface abort	810–895 sec
Preferred liftoff time	980 sec

If the crew cannot wait for the 980-second preferred liftoff time (for example, in the case of a probable tipover), the abort can be done immediately. The phasing, however, will not be as good as if the crew had waited the full 980 seconds.

Targets for a lunar-surface abort are the same as powered-descent-abort targets. But the ground supplies data for the crew to perform a P30–P41 boost maneuver at perilune in order to change the apolune from 30 to 52 n. mi., making this lunar-surface abort equivalent to a nominal ascent (P12) from the lunar surface. (Refer to paragraphs 3.3.1.1 and 3.3.1.2.)

Note that when P71 is called via VERB 37, the DPS will not be automatically staged. Thus, the crew must manually stage the DPS before using VERB 37 to enter P71. P71 has no way of determining if the DPS has been staged or not. As a result, if the DPS has not been manually staged, P71 will give the engine-on command to the DPS instead of the APS. If P71 is called by depressing the ABORT STAGE pushbutton, the DPS will be staged automatically.

Once P71 is called, the ABORT ENABLE flag is reset to zero, prohibiting further calls to P70 or P71. The OPR ERR light illuminates if an attempt is then made to call either P70 or P71 via VERB 37.

3.3.3.1 Related Routines and Extended Verbs

The routines associated with P71 are listed below and briefly explained.

a. R11 is the Abort Discretes Monitor Routine. (Refer to paragraph 3.3.2.2.2.)
b. R10 is the Landing Analog Display Routine. (Refer to paragraph 3.3.2.2.1.)
c. R40 is the DPS/APS Thrust Fail Routine. (Refer to paragraph 3.3.3.1.1, below.)
d. R47 is the AGS Initialization Routine. (Refer to paragraph 3.3.2.2.4 for an explanation of R47.)

3.3.3.1.1 <u>DPS/APS Thrust Fail Routine (LM R40).</u>—The crew should follow procedures outlined for DPS thrust failure during the DPS Abort (P70), noting that the threshold value for the Δv comparison, set by P71, is 308 cm/sec. Also note that references to the throttle in the DPS thrust-failure procedures do not apply to P71.

Table 3.3.3-I lists the extended verbs that may be used during P71.

3.3.3.2 Computational Sequence

The APS abort can be used either as a primary abort or as a follow-up to P70. The thrust-filter initialization is the same for both uses of P71. But this initialization differs from P70 in that the engine performance parameters are prestored in the LGC. The initialization of t_{go}, however, differs in the two uses of P71. When P71 is used as a primary abort, the initial t_{go} calculation is the same as the t_{go} for P70. When P71 is used as a follow-up to P70, a working value of t_{go}, made available by P70, is used. This value must then be doubled to account for the lower acceleration of a full ascent stage during P71, as compared to the empty descent stage at termination of P70. Also, when P71 is used as a follow-up to P70, the target initialization is by-passed since it was previously done by P70.

Table 3.3.3-II lists the displays associated with P71. Figure 3.3.3-1 is a flowchart of P71. The flowchart and the tables should be referenced when reading the computational sequence detailed below.

The APS Abort Program is called by depressing the ABORT STAGE pushbutton or by keying VERB 37 ENTR 71 ENTR into the DSKY. If P71 is incorrectly selected

TABLE 3.3.3-I

EXTENDED VERBS USED WITH APS ABORT (LM P71) (SHEET 1 OF 2)

VERB	Identification	Purpose	Remarks
60 ENTR	Display PGNCS-derived vehicle attitude rates.	Display the attitude rates on the FDAI error needles.	This display may be selected at any time during P71. Vehicle rates are available, however, only when the DAP is turned on.
61 ENTR	Display Mode I DAP attitude errors.	Display on the FDAI error needles the difference between the current CDU and the DAP command angles.	This process can be selected by the crew any time during P71. The crew can use Mode I error display to monitor the DAP's ability to track automatic steering commands.
62 ENTR	Display Mode II total attitude errors.	Display on the FDAI error needles the total attitude error—(NOUN 22) desired ICDU angles minus (NOUN 20) present ICDU angles.	This process can be selected by the crew any time during P71. The crew can use Mode II error display to assist them in manually maneuvering the LM.
76 ENTR	Minimum Impulse Command Mode.	Enables the Minimum Impulse Mode of the DAP. The crew can then perform manual attitude control about all the vehicles axes with the ACA in the Minimum Impulse Mode.	Extended VERB 76 can be selected by the crew at any time. The crew must put the GUID CONT switch to PGNS and the MODE COUNT switch to ATT HOLD. The Minimum Impulse Mode will remain enabled until canceled by the rate command selection (Extended VERB 77) or a fresh start. It is strongly recommended that no powered flight maneuver be attempted in this Minimum Impulse Mode. The Minimum Impulse Mode is also canceled when P71 is first entered.

TABLE 3.3.3-I

EXTENDED VERBS USED WITH APS ABORT (LM P71) (SHEET 2 OF 2)

VERB	Identification	Purpose	Remarks
77 ENTR	Rate Command and Attitude Hold Mode.	Enables the Rate Command Mode of the DAP and sets the desired ICDU angles equal to the actual ICDU angles. The crew can then perform manual attitude maneuvers about all vehicle axes with the ACA in the Rate Command Mode.	Extended VERB 77 can be selected by the crew at any time. The Rate Command Mode will remain enabled until canceled by the Minimum Impulse Mode (see Extended VERB 76). The GUID CONT and MODE CONT switches should be set in the same way as in Extended VERB 76. Note that the Rate Command Mode is established at DPS ignition in P63 and when P71 is first entered.
82 ENTR	Orbital Parameter Display Routine (R30)	Provides the crew with pertinent orbital parameters computed by the LGC, updated every 2 seconds during AVERAGEG, to supplement orbital information provided by the ground.	Extended VERB 82 is manually selected by the crew after the engine is shut down in P71, and the LM has achieved an orbit. If TFF is not computable (perilune altitude is greater than 35,000 ft) the LGC will set TFF equal to -59B59, compute TF PER and store it in NOUN 32, which the crew can call also.

TABLE 3.3.3-II

APS ABORT DISPLAYS (LM P71) (SHEET 1 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
FL V37	R00	Request astronaut to select program (if ABORT STAGE pushbutton not used)		
FL V50 N25	P71	Request desired modes for guidance and attitude control for APS abort be selected as follows: GUID CONT → PGNS ATT CONT → AUTO	ENTR - bypass request PRO - accept request by changing modes first	R1 00203_8 R2 Blank R3 Blank
V06 N94	P71	Display data for monitoring APS abort.	VGX-X-component of LM velocity-to-be-gained vector HDOT-rate of altitude change H-altitude	R1 xxxx. x fps R2 xxxx. x fps R3 xxxxx ft
V05 N09 E	Astronaut (FINDCDUW routine)	Verify program alarm	00401 - desired middle gimbal angle exceeds 70 deg. 00402 - FINDCDUW not controlling attitude	R1, R2, R3 } xxxxx*
FL V16 N94	P71	Informs crew of APS engine shutdown	Same as V06 N94 data	R1 xxxx. x fps R2 xxxx. x fps R3 xxxxx ft
FL V16 N85 or V16 N85 E**	P71 or Astronaut	Monitor $\underline{v}_G$ components remaining during the APS burn; after APS shutdown to monitor the $\underline{v}_G$ residuals during RCS trimming.	VGX-X-component of $\underline{v}_G$ VGY-Y-component of $\underline{v}_G$ VGZ-Z-component of $\underline{v}_G$	R1 xxxx. x fps R2 xxxx. x fps R3 xxxx. x fps

* Refer to note in paragraph 3.3.1.6.

** V16 N85 can be keyed in anytime during the APS abort.

TABLE 3.3.3-II

ABORT DISPLAYS (LM P71) (SHEET 2 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
V06 N76 E	Astronaut	Display targeting information	ZDOTD-downrange velocity RDOTD-radial velocity Crossrange	R1 xxxx. x fps R2 xxxx. x fps R3 xxxx. x n. mi.
V16 N77 E	Astronaut	Display additional components to be used in monitoring APS engine shutdown	TG-estimated time of flight from present to injection (-polarity) VGẎ-Y-component of $\underline{v}_G$ VI-magnitude of LM inertial velocity	R1 xxBxx min, sec R2 xxxx. x fps R3 xxxx. x fps
V82 E *	Astronaut	Call R30, the Orbital Parameter Display Routine	- - -	- - -
FL V16 N44	R30	Display orbital parameter information to supplement ground information	Apolune altitude of LM orbit Perilune altitude of LM orbit Time of free fall to 35, 000 ft.	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min, sec
(FL) V06 N32 E ** or (FL) V16 N32 E	Astronaut	Display time from perilune ***	TF perilune	R1 ooxxx hr R2 oooxx min R3 oxx. xx sec

* VERB 82 can be keyed in after APS shutdown (i. e. FL V16 N94)

** NOUN 32 display flashes if keyed in over a flashing display. V16 or V06 can be used to call the NOUN 32 display.

*** If TFF is not computable, i. e., perilune exceeds 35, 000 ft., the LGC sets TFF to - 59B59 and computes TF perilune storing it in the NOUN 32 display.

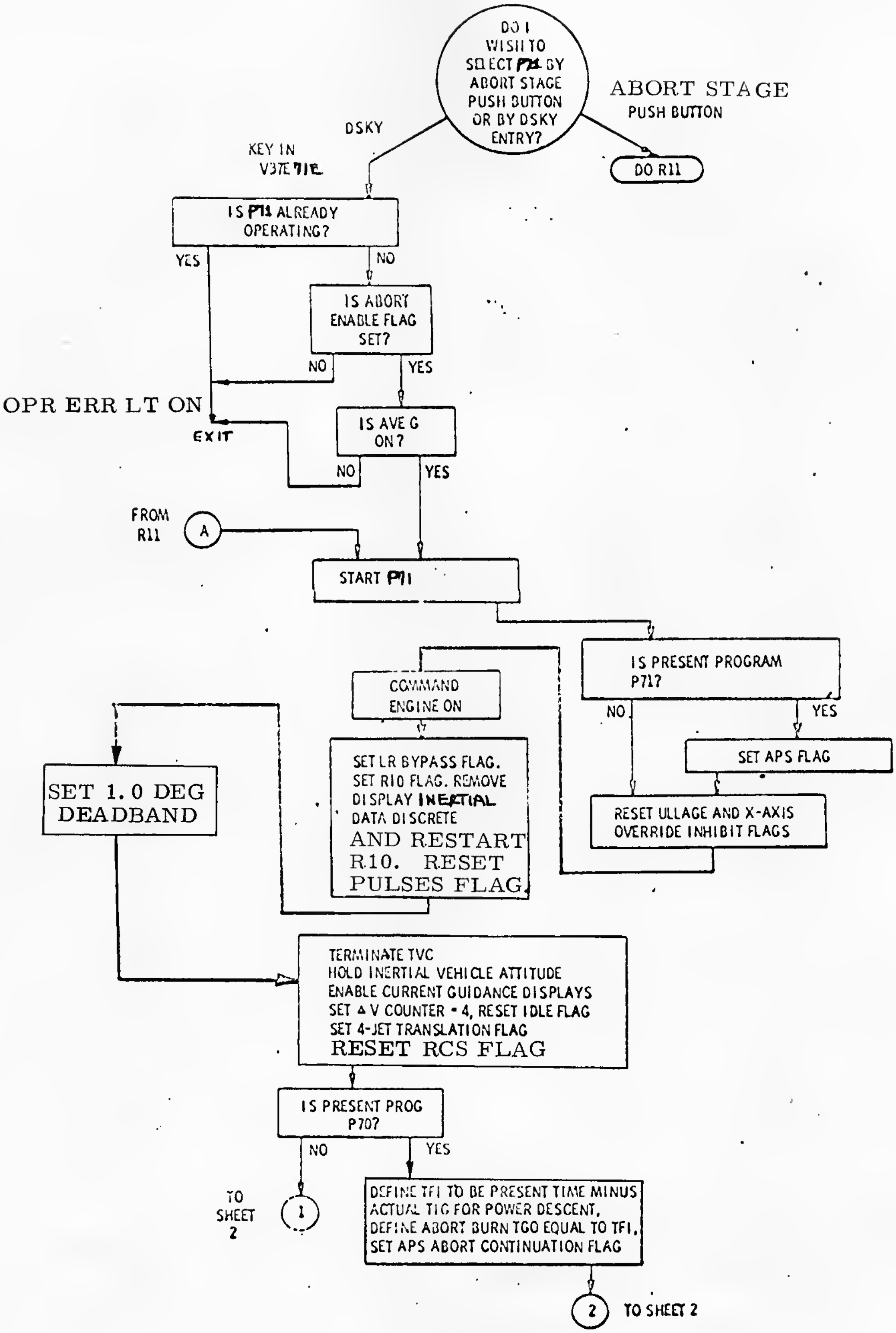

Figure 3.3.3-1. Ascent Propulsion System Abort (LM P71) (Sheet 1 of 6)

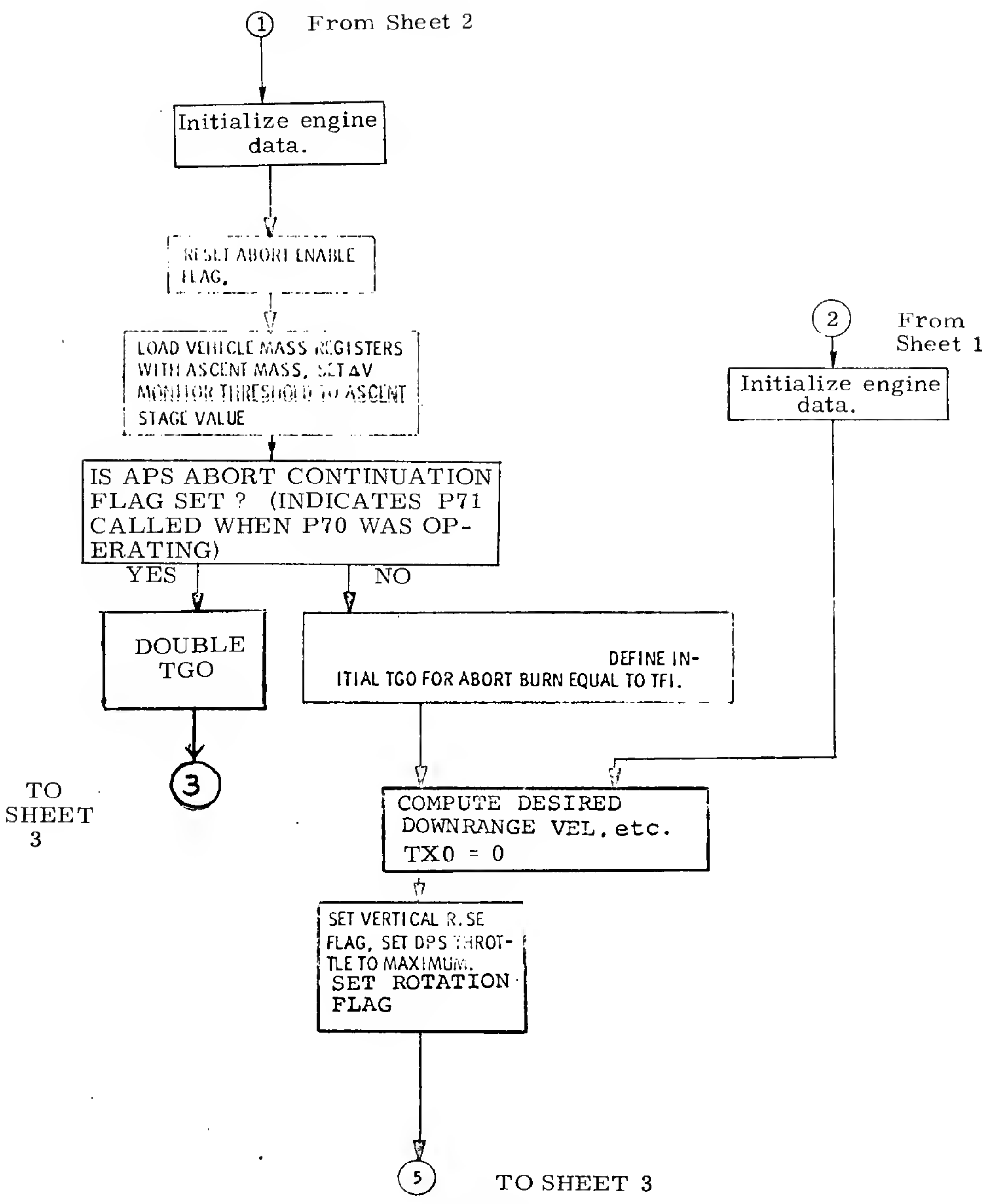

Figure 3.3.3-1. Ascent Propulsion System Abort (LM P71) (Sheet 2 of 6)

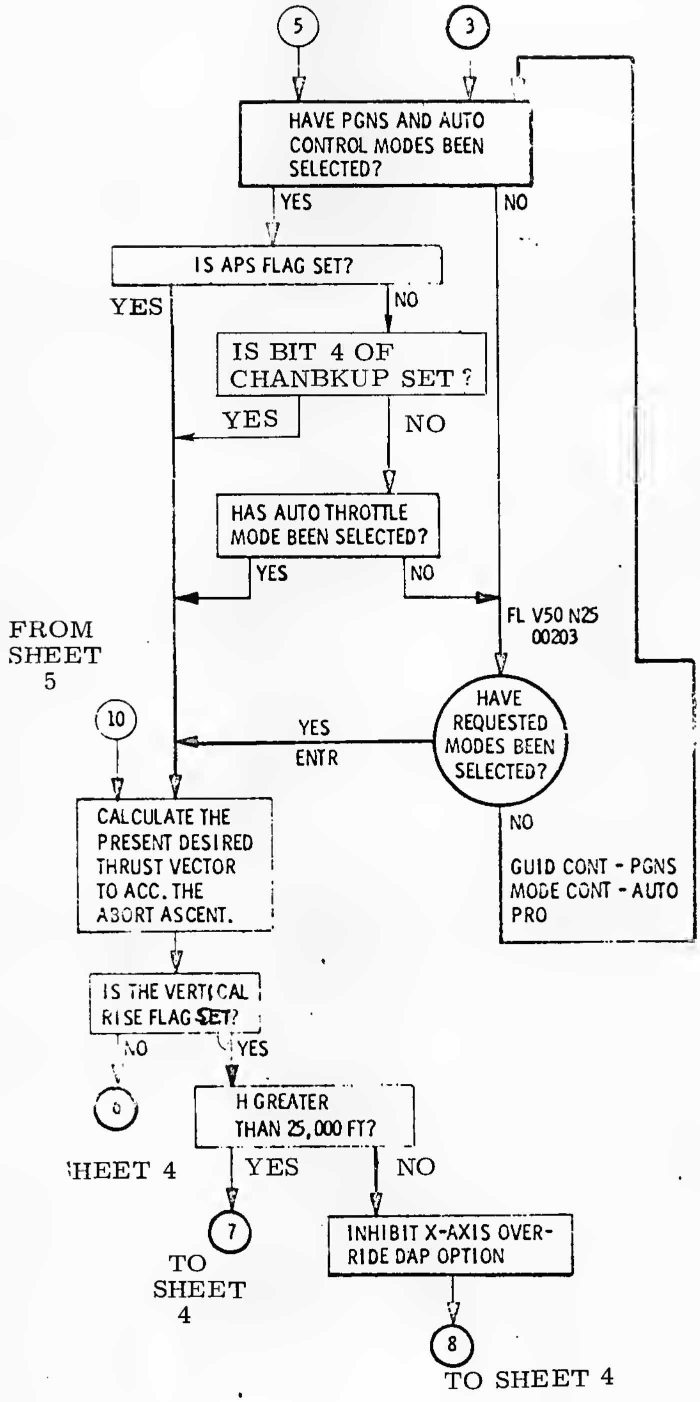

Figure 3.3.3-1. Ascent Propulsion System Abort (LM P71) (Sheet 3 of 6)

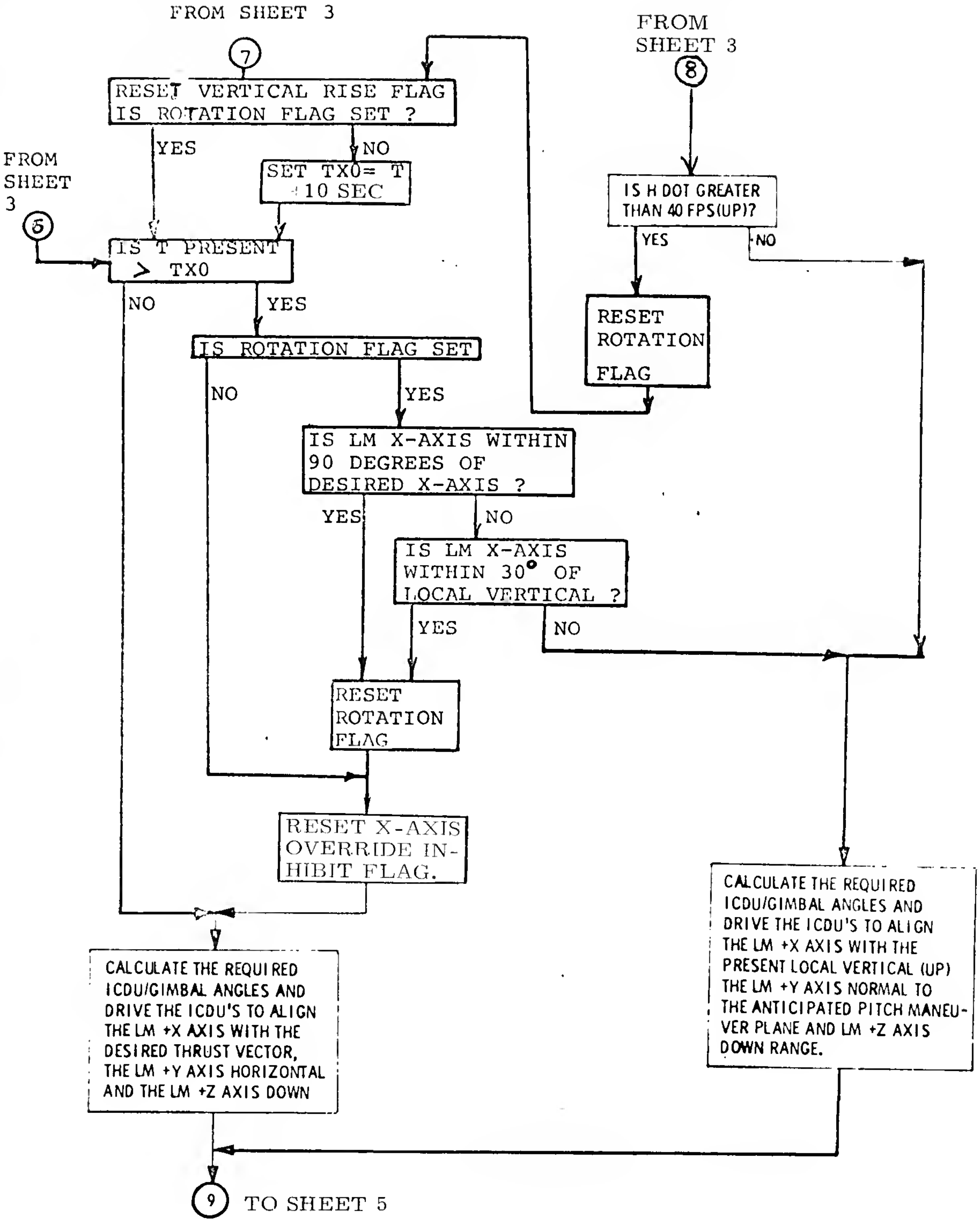

Figure 3.3.3-1. Ascent Propulsion System Abort (LM P71) (Sheet 4 of 6)

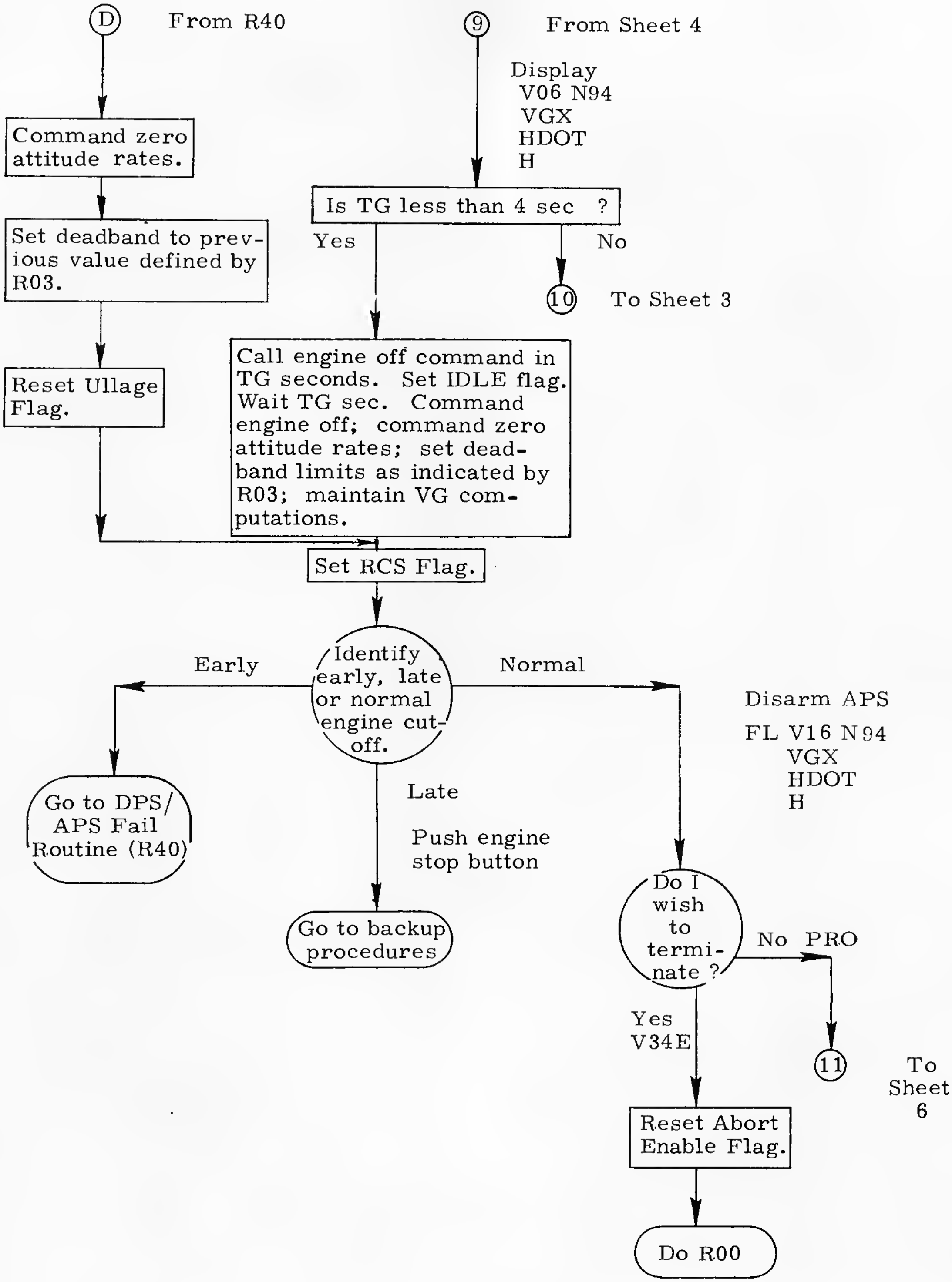

Figure 3.3.3-1. Ascent Propulsion System Abort (LM P71) (Sheet 5 of 6)

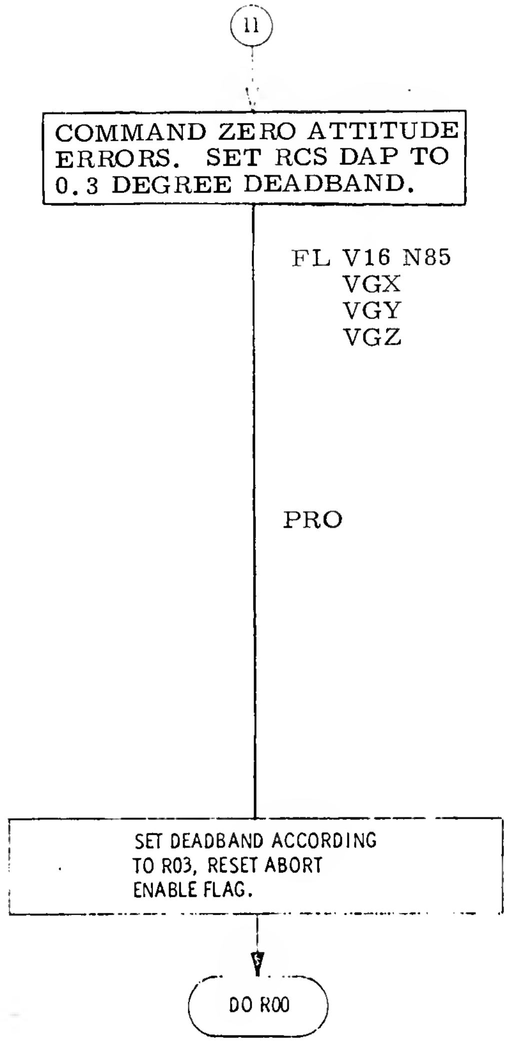

Figure 3.3.3-1. Ascent Propulsion System Abort (LM P71) (Sheet 6 of 6)

because of one of the following reasons, the OPR ERR light will be illuminated informing the crew of the error:

a. P71 is already in progress.
b. The ABORT ENABLE flag is reset.*
c. P68, the Landing Confirmation Program, was called prohibiting calls to P71.
d. The AVERAGEG flag is not set.

Otherwise, 71 is displayed on the DSKY indicating that the APS P71 has started. After a few flags are appropriately set for the APS abort, the APS engine is commanded on by P71. Note that if a total thrust failure occurs, the crew must apply manual RCS translation until P71 automatically commands the APS engine on. If the crew —before selecting the APS abort—was in the process of landing the LM, the LGC has to remove the inertial data discrete from the CDUs and restart R10, the Landing Analog Display Routine. In addition, the LGC also controls the following processes:

a. Sets 1.0 degree deadband
b. Terminates thrust vector control
c. Holds inertial vehicle attitude
d. Sets the Δv counter to 4 for use by R40, the DPS/APS Thrust Fail Routine
e. Enables the current guidance displays
f. Resets IDLE and RCS flags
g. Sets the 4-jet translation flags
h. Sets the Δv monitor threshold to ascent stage values.

Then the LGC calculates the initial t_{go} for the APS abort and resets the ABORT ENABLE flag. If P71 is called as a follow-up to P70, the value of t_{go} will be twice that of the t_{go} that P70 most recently calculated. The initial target conditions** for the APS abort are set up if P71 has been called as a primary abort, but the targeting initialization is bypassed if the APS abort is a follow-up to the DPS abort. See paragraph 3.3.2.1 for a description of the abort targets.

During the time the above calculations are being performed by the LGC, the crew can set the GUID CONT switch to PGNS and the PGNS MODE CONTROL switch to AUTO. If P71 is used as a follow-up to P70, these switches should already have

*P63 sets the ABORT ENABLE flag; P71 resets the flag.

**t_{go} is set equal to the present time minus the actual t_{IG} for powered descent.

been set as indicated above. If not, that is, if P71 is being used as the primary abort, a flashing VERB 50 NOUN 25 with R1 set to 00203 appears on the DSKY requesting that the crew "please perform" the switch settings. If to be ignored, the crew keys ENTR to continue P71, bypassing the request. To comply with the request, the crew makes proper settings and keys PRO to continue.

The LGC then calculates the present desired thrust vector to accomplish the abort ascent conditions and determines if a vertical rise and pitchover maneuver is required. (An explanation of vertical rise and pitchover can be found in subsection 3.3.)

Regardless of whether the LM enters the vertical rise and pitchover phases or not, the LGC next calculates the required ICDU/gimbal angles and drives the ICDUs to align the LM +X-axis appropriately.

During the APS abort, the crew monitors the DSKY, the FDAI, and looks out the window. During the entire APS burn, the DSKY displays VERB 06 NOUN 94 containing values of the x-component of the velocity-to-be-gained vector, the rate of altitude change, and the present altitude. If, when the abort is called, the altitude is greater than 25,000 ft on the first pass through the guidance, the X-axis-override option is <u>not</u> inhibited for the remainder of the ascent. If the altitude is less than 25,000 ft on the first pass, however, the X-axis-override option is inhibited. In this case, the option can become available on subsequent passes through the guidance under either of the following conditions:

a. If the radial rate exceeds 40 fps (up) before the altitude exceeds 25,000 ft, a timer is set to permit X-axis override in 12 sec.
b. If the altitude exceeds 25,000 ft before the radial rate exceeds 40 fps (up), the option remains inhibited until either the 30- or the 90-deg rotational test is passed. The override option then becomes available immediately.

When either of these conditions is satisfied, the PGNCS pitches the LM to the correct attitude to perform the ascent abort and once again restores the X-axis-override option to the crew. The above maneuvers are done with the RCS jets.

While monitoring the DSKY display of VERB 06 NOUN 94, the crew should observe the FDAI attitude errors and attitude rates; monitor the APS chamber pressure; and then prepare for APS engine shutdown, identifying early, late, or normal cutoff.

If the target conditions are not met, and the APS is shut down early, the crew sees a flashing VERB 97 display from R40 indicating thrust failure. Responding appropriately to the flashing VERB 99 display in R40 (see paragraph 3.3.3.1.1), the crew either attempts to re-ignite the APS, or completes the abort ascent using the RCS jets. To obtain an approximation to APS engine shutdown the crew can monitor either VGX in NOUN 94, or TG in NOUN 77. When the APS is shut down by P71, the VERB 06 NOUN 94 automatically changes to flashing VERB 16 NOUN 94.* In response to this flashing display, the crew disarms the APS and, if desired, keys PRO to display flashing VERB 16 NOUN 85 on the DSKY and observe the velocity residuals, VGX, VGY, VGZ—possibly nulling them out by an RCS trim maneuver. (NOUN 85 can be called anytime during the abort maneuver. See paragraph 3.3.2.6 on use of RCS jets in P70–P71 aborts.) Alternatively, the crew can key VERB 34 ENTR (terminate) to end P71, or key VERB 82 ENTR to call R30, the Orbital-parameters Display Routine to monitor continuous updated values of apolune, perilune, and TFF. The crew can also terminate P71 by keying PRO or VERB 34 ENTR in response to the flashing VERB 16 NOUN 85 display, when satisfied with the velocity residuals.

3.3.3.3 Alarms

The alarms listed below may occur during P71.

a. Alarm 00401 may occur as a warning of impending gimbal lock.
b. Alarm 00402 may occur if FINDCDUW is not controlling attitude.

Refer to paragraph 3.3.2.4 for a detailed explanation of the above alarm codes.

3.3.3.4 Restarts

P71 is restart protected. For most software restarts, the PROG alarm light illuminates, and the program goes back to the last flashing display before the restart. For hardware restarts, the RESTART light on the DSKY illuminates.

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* Note that if engine shutdown for the APS is identified as being later than desired, the crew should depress the engine STOP pushbutton.

SECTION 4.0

COASTING FLIGHT NAVIGATION

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4.1 INTRODUCTION TO COASTING FLIGHT NAVIGATION

Navigation during coasting flight is accomplished by onboard processing of optics and VHF data in the Command and Service Module (CSM), and of radar data in the Lunar Module (LM). The data contribute to maintaining current estimates of the CSM and LM state vectors.

The CSM coasting flight navigation programs are as follows:

- P20 Universal Tracking and Rendezvous Navigation (paragraph 4.2.1)— Options 0 and 4
- P21 Ground-track Determination (paragraph 4.2.2)
- P22 Orbital Navigation (paragraph 4.2.3)
- P23 Cislunar Navigation (paragraph 4.2.3)
- P24 Rate-aided Optics (paragraph 4.2.6)
- P29 Time of Longitude (paragraph 4.2.7)

In the LM there is no need for cislunar navigation, and orbital navigation is replaced by lunar surface navigation. The LM navigation programs are the following:

- P20 Rendezvous Navigation (paragraph 4.3.1)
- P21 Ground-track Determination (paragraph 4.3.2)
- P22 Lunar-surface Navigation (paragraph 4.3.3)
- P25 Preferred Tracking Attitude (paragraph 4.3.4).

Although the two update programs (CSM P27 and LM P27) are included in this section, the navigation theory discussed in this introduction pertains to neither.

4.1.1 Mission Phases

Coasting flight navigation can be used during the following mission phases: cislunar (CSM), rendezvous, lunar prelaunch (LM), earth and lunar orbit (CSM).

4.1.1.1 Cislunar Navigation

Cislunar navigation is used to maintain state-vector estimates during translunar and transearth coast. The computed state-vector data provide the basis for onboard targeting of transearth trajectories outside the moon's sphere of influence. Cislunar navigation is used primarily as a backup mode since the trajectories are usually ground-targeted, using ground-computed state vectors.

Optical sightings of the angle between the directions to a star and to a planetary horizon or landmark supply data for modifying or updating the state vector. From the measured angle and the time of the sighting, the command module computer (CMC) determines the state-vector estimate. The CMC processes the angle-measurement data immediately after the measurement is made and displays the values for approval before the state vector is updated. Bad updates can be avoided by rejecting the values when they are displayed.

4.1.1.2 Rendezvous Navigation

During the rendezvous phase, estimates of both state vectors (LM and CSM) are stored in both vehicle computers (LGC and CMC). Rendezvous navigation is used to update one of the two state vectors (usually the LM's) in both vehicles. Only one state vector is updated because limited computer storage precludes updating both states. This, however, provides satisfactory rendezvous navigation since accurate knowledge of the relative state (knowledge of one state with respect to the other) is the primary concern in rendezvous.

The CSM-based sensors provide two types of tracking data: optical data, acquired manually with the sextant and the COAS; VHF range-link data, acquired automatically. In the LM, tracking data are gathered from the rendezvous radar (RR). Either onboard system has the complete capability of providing the crew with the necessary data, computations, and control to perform the rendezvous without inflight assistance from the ground or the other vehicle's system.

4.1.1.3 Lunar-surface Navigation

During the final CSM orbits prior to launch from the lunar surface, the LM can use lunar-surface navigation to update its estimate of the CSM state vector.

Range and range-rate data* are obtained from the RR as the CSM passes in its orbit. A rapid mark-taking sequence of approximately 3.5 sec can be accomplished by inhibiting update and using the marks for downlink transmission. Otherwise, the maximum frequency of update for each mark—when done onboard—is approximately once every 13 sec.

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*RR angular data are not incorporated in the estimate due to uncertainties associated with the magnitude and nature of the RR angle biases.

The LGC establishes an estimate of the CSM state vector relative to the LM's known position and velocity as a prologue to LM rendezvous navigation, which begins after the LM'S ascent from the lunar surface.

4.1.1.4 Orbital Navigation

While the CSM is in earth or lunar orbit, orbital navigation can be used to maintain the CSM state-vector estimate or to refine knowledge of the location of a point on the surface. The state vector is expanded to nine dimensions during orbital navigation in order to include the estimated landmark position vector, the CSM position vector, and the CSM velocity vector.

Tracking data are obtained from optical measurements of the angles between the IMU stable member and lines of sight to a point on the surface. Processing of the data is done by the ground or, in some instances, onboard the spacecraft. Since the landmark remains visible to the orbiting vehicle for a limited time, a number of sets of optical angle data, or tracks, are acquired on each pass. These data are directly telemetered for immediate processing (P24 and P22).

4.1.2 Recursive Navigation

Navigation in all these phases is accomplished by a procedure known as recursive navigation, a technique that uses the current state-vector estimate plus measurements to compute a new, updated estimate, then uses the new estimate and new measurements to compute another estimate, and so on. An essential part of recursive navigation is the use of a Kalman filter* to process the sensor data incorporated in each update. Kalman filtering is a technique for obtaining an optimum estimate by combining measured data with predicted data. When the difference between the measured and predicted values is multiplied by a weighting vector ($\underline{\omega}$), a correction is obtained for updating the state vector.

The four principal factors involved in this process are (1) extrapolation, (2) measurement geometry, (3) statistical weighting, and (4) error correlation. Levine** represents the interrelationship of these elements as an ellipsoid of six dimensions

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*Battin-Levine E-note 2401, "Application of Kalman Filtering Techniques to the APOLLO Program"

**SGA Memo No. 11-68 Gerald M. Levine, "Recursive Navigation Theory Explained"

(for three position components and three velocity components). The ellipsoid geometrically defines the area of one-sigma error probabilities. The changing size and shape of the idealized ellipsoid during navigation illustrate the dynamic behavior of the error matrix used in the Kalman filter computations.

To make a valid comparison of measured and predicted values, the AGC extrapolates the current state vector to the time of measurement, and a prediction is made as to the new estimate. (The statistical error ellipsoid associated with the state vector is also extrapolated. Between measurements, the error model should grow and rotate.) If the measured and predicted values agree, the extrapolated state vector is assumed correct; if the measured and predicted values do not agree, the extrapolated state vector is assumed to require some correction.

The role geometry plays is idealized one-dimensionally in Figure 4.1.2-1. Given perfect knowledge of the spacecraft orbit, a unique point P in that orbit can be inferred at time t by measuring the angle A between the fixed reference direction ($\overline{D}$) and the line of sight to a known point T. If the angle measurement were perfect, the point P would be the true orbital position.

Since it would be unrealistic to believe entirely in the measurement data and not at all in the predicted data, a <u>statistical</u> <u>weighting</u> model must be provided to determine the relative credibility of the two sets. Also, since in some instances data may be measured for only one dimension, a means must be provided for correlating the results to the unmeasured dimensions. The procedure for doing this can be visualized by considering an ellipse (Figure 4.1.2-2a) whose semi-major and semi-minor axes, respectively, lie along, and normal to, the line of sight to the target body; the size and shape of the ellipse E reflect the one-sigma error probability in the estimated position P.

Because state vector errors change with extrapolation, the size of E generally increases with time until a measurement is taken to restore confidence. New information causes E to shrink in the direction effected by the measurement (in Figure 4.1.2-2a, the direction normal to the line of sight). If there were no measurements, E would be continuously expanding. As a result of making measurements in a single direction, E becomes less circular. Without correlation, each measurement would cause E to become smaller in the direction normal to the measurement LOS, while E continued to grow in the direction of the LOS. The error model, however, rotates at a different rate than does the vehicle's state vector. After a period of extrapolation, the axes of an idealized ellipse would have rotated

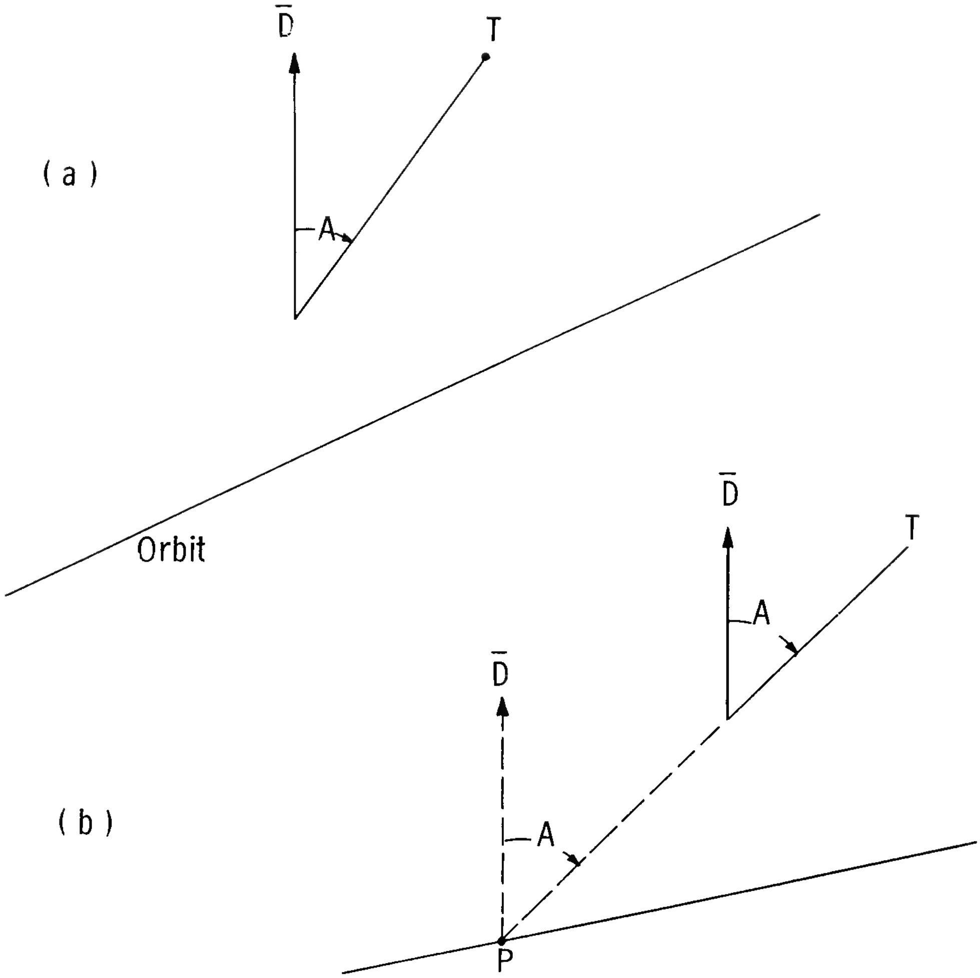

Figure 4.1.2-1. One-dimensional Example of Geometric Determination in Recursive Navigation

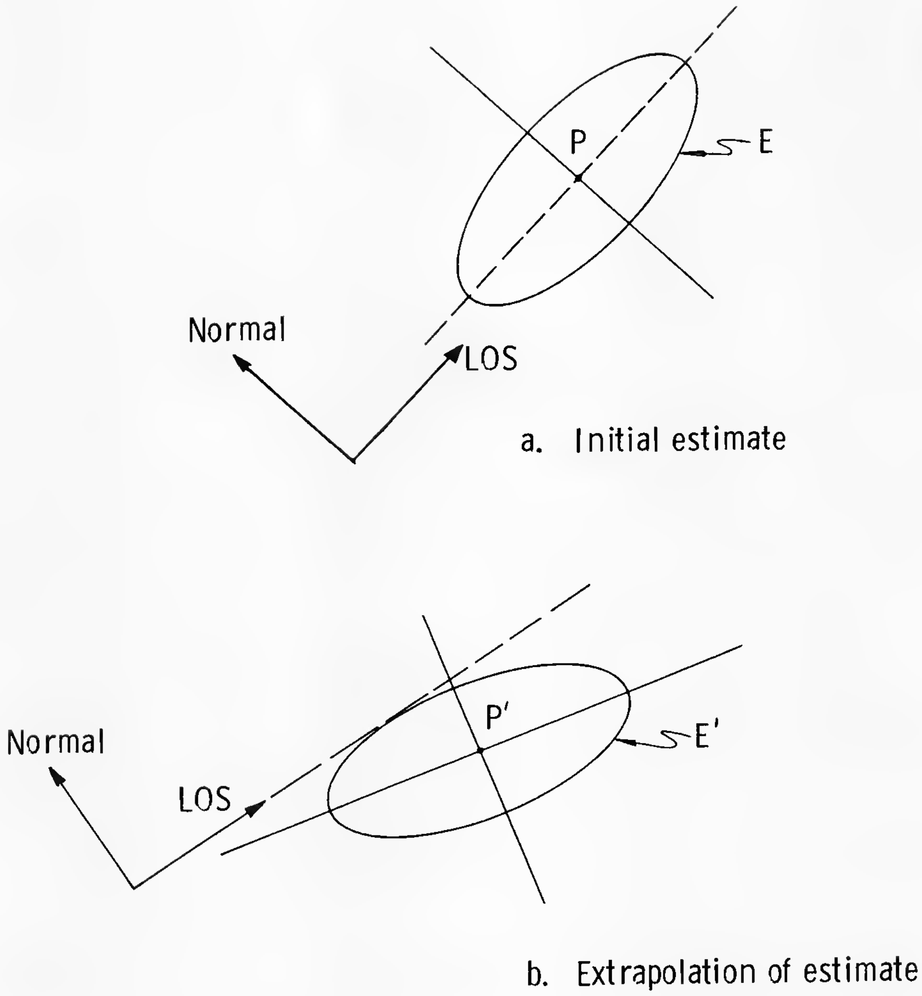

Figure 4.1.2-2. Two-dimensional Example of Extrapolation

off the LOS, as shown in Figure 4.1.2-2b. A new measurement along the LOS would shrink both axes of the ellipse, thus the statistical error in the unmeasured direction is correlated to the measured direction. The amount of correlation depends on the amount of relative rotation between the state vector and the error model; the relative rotation depends on the eccentricity of the vehicle orbit. For example, at the end of transearth coast, correlation is very poor because the path of the vehicle is almost a straight line.

The interrelationship of the four principles of recursive navigation is presented in Figure 4.1.2-3. In Figure 4.1.2-3a, the point P represents the best estimate of spacecraft position at time t. The ellipse E circumscribes the one-sigma error probability associated with P. In Figure 4.1.2-3b, P' represents the spacecraft position extrapolated to time t'. As a result of the extrapolation, the error ellipse (E') associated with P' has enlarged slightly and rotated. A new measurement establishes the line of geometrical agreement (L_2). With perfect confidence in the measurement, P_2 would be assumed as the precise spacecraft location.

Statistical weighting of the difference between P_2 and P', however, results in the designation of Q as the most probable location—ignoring the unmeasured dimension. The measured and unmeasured dimensions are correlated by constructing L' parallel to L_2, through Q. The one point of L' that is tangent to the smallest ellipse of constant probability centered at P' is the new best estimate P_2'. Figure 4.1.2-3c shows the cycle completed with P_2', the new best estimate, and its reoriented and slightly smaller error ellipse E_2.

The statistical data describing the error ellipsoids are stored in the AGC as a six-dimensional matrix (nine-dimensional if the state vector is of nine dimensions) reflecting the covariances between the elements of the state vector inherent in the estimates. For computational convenience,* the error-transition matrix (W-matrix) is used rather than the covariance matrix (E-matrix); the W-matrix is essentially the square root of the E-matrix.

As the computational error ellipsoid, the W-matrix helps to provide correlation between errors in the direction of sensor measurements and errors in other directions not specifically measured. Over a period of time with several tracking measurements, the total correlation of errors in all directions will improve, as will the ability of the filter to reduce errors in unmeasured directions.

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*As explained in E-2401

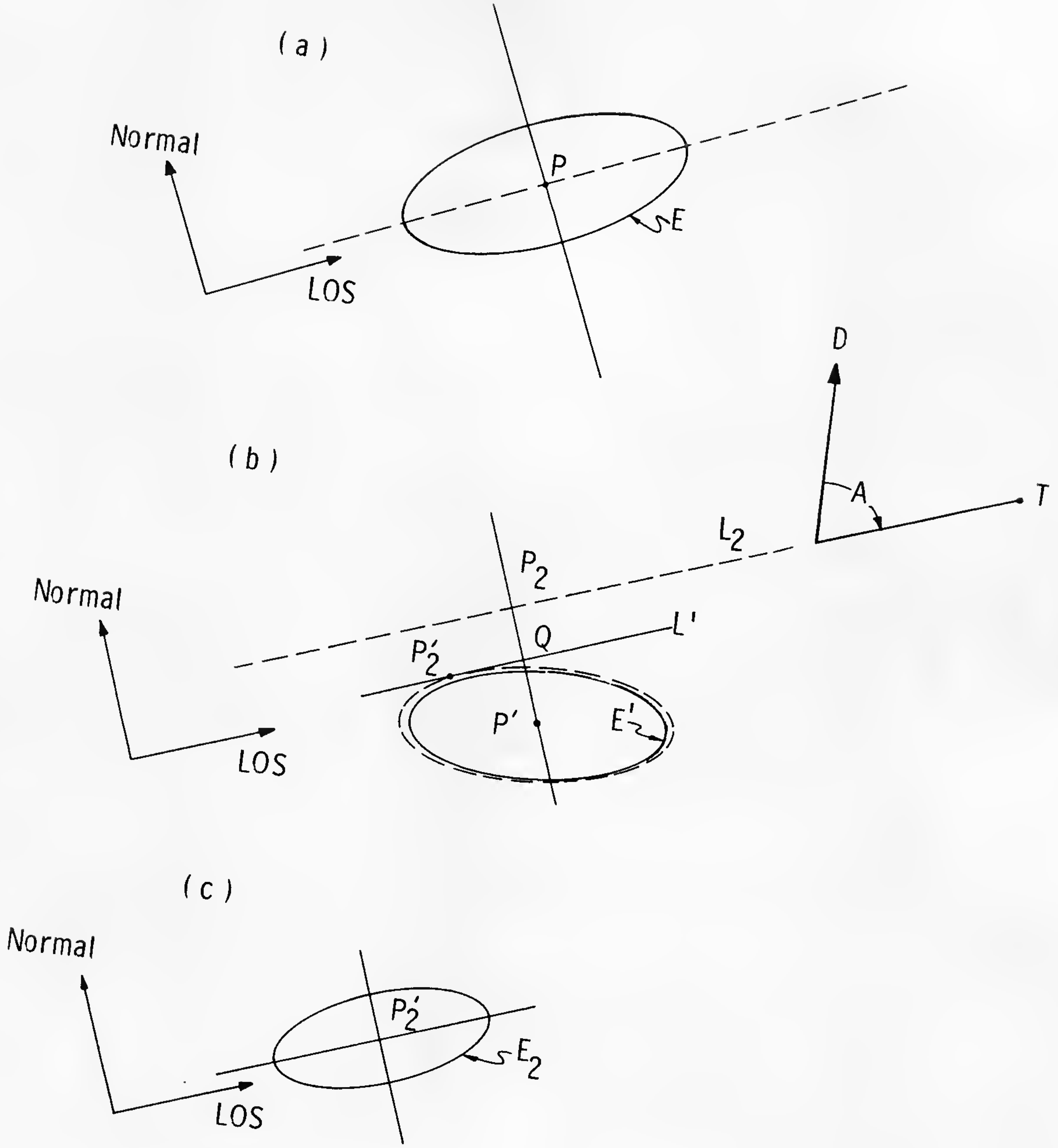

Figure 4.1.2-3. Two-dimensional Example of Correlation

Because of incomplete error modeling, as well as computer storage limitations and numerical problems of extrapolation, there is a gradual and inevitable decay of the elements of the W-matrix. Between measurements, the W-matrix tends to grow at too slow a rate, and then decreases as the result of incorporation of new data. Eventually, therefore, all new data would be ignored simply because they would be given a weighting factor of zero (thus giving the false impression that knowledge of the state vector could not be improved by new data). Consequently, the W-matrix must be periodically reinitialized (to predetermined expected values of position and velocity errors).* The timing of reinitialization is discussed in each program where applicable.

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*In cislunar navigation the modeling is more accurate (since there is only one vehicle), and reinitialization is unnecessary.

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SUBSECTION 4.2

CMC COASTING FLIGHT NAVIGATION PROGRAMS

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4.2.1 P20, Universal Tracking and Rendezvous Navigation—CMC

The CMC Universal Tracking and Rendezvous Navigation Program (P20) has two independent functions—tracking and navigation. The tracking function applies to any mission situation requiring the CSM to track a designated body with a specified pointing vector or to any mission situation requiring the CSM to rotate at a constant rate around a specified vector. The navigation function applies only to the Rendezvous Navigation Mode of P20.

Regardless of function, P20 can always be started by the conventional VERB 37 ENTR 20 ENTR. If the Rendezvous Navigation Mode is to be used, however, the simplest way to start P20 is by calling an appropriate Rendezvous Targeting Program. (See paragraph 4.2.1.2.) Depending upon the tracking option selected, P20 continues in the background when the crew selects any of the navigation, targeting, or alignment programs listed (with allowable options) in Table 4.2.1-I. Only the rendezvous targeting programs (P31–36) and the Rendezvous Final Program (P79), however, start P20 if it is not already running. (Refer to Figure 4.2.1-1 for a flow diagram of P20 initial conditions. The figure also lists the conditions of "permanent" P20 termination.) The nominal use for each of the P20 starting conditions is as follows:

Initial Condition	Use
A	To select P20 nonrendezvous options (1, 2, or 5)
B	To return to P20 (nonMINKEY) from another program
C	To initiate rendezvous mode of P20 (MINKEY or Manual)
D	To initiate MINKEY when P20 rendezvous mode (Manual) is operating
E,F	To continue P20 (nonMINKEY) in background of another program

Observe that Initial-condition A is the primary condition for initiating the P20 Nonrendezvous Mode, that Initial-condition C is primary for initiating the P20 Rendezvous Mode.

4.2.1.1 P20 Nonrendezvous Mode

The nonrendezvous mode of P20 comprises Options 1, 2, and 5. Options 1 and 5 allow the crew to specify any spacecraft vector and DAP deadband and have the program compute and execute an attitude maneuver for pointing the specified vector

TABLE 4.2.1-I

PROGRAMS ALLOWING P20 TO RUN IN BACKGROUND

Program Number	Compatible Options				
	0	1	2	4	5
P21*	X	X	X	X	X
P22		X	X		X
P24		X	X		X
P27		X	X		X
P29*	X	X	X	X	X
P30	X	X	X	X	X
P31-P36	X			X	
P52			X		
P54			X		
P72-P75	X	X	X	X	X
P79*				X	

*Tracking only (no navigation)

Options

0.....Point a specified spacecraft vector at the LM. Do not constrain rotational attitude about this pointing vector. (Use VECPOINT.)

1.....Point a specified spacecraft vector at a celestial body. Do not constrain attitude about this vector. (Use VECPOINT.)

2.....Rotate at a specified rate about a specified spacecraft vector.

4.....Same as Option 0, but constraining attitude about the pointing vector to a specified value (OMICRON).

5.....Same as Option 1, but constraining attitude about pointing vector to a specified value (OMICRON).

Initial-condition A. —VERB 37 ENTR 20 ENTR when P20 is either active* and in PROG lights or not active.

Initial-condition B. —VERB 37 ENTR 20 ENTR when P20 is active* but not in PROG lights, i.e., temporarily terminated or running in the background.

Initial-condition C. —VERB 37 ENTR xx ENTR when the rendezvous mode of P20 is inactive* and where xx is the number of a MINKEY-compatible program (P31–P36, P79).

Initial-condition D. —VERB 37 ENTR xx ENTR when the rendezvous mode of P20 is active* and where xx is the number of a MINKEY-compatible program (P31–P36, P79).

Initial-condition E. —VERB 37 ENTR xx ENTR when the rendezvous mode of P20 is active* and where xx is the number of a P20-compatible program that is incompatible with MINKEY.

Initial-condition F. —VERB 37 ENTR xx ENTR when the nonrendezvous mode of P20 is active* and where xx is the number of a P20-compatible program.

---

*Once P20 is started, by any means, it is considered active until "permanently" terminated by one of the following:

- VERB 96 ENTR
- VERB 56 ENTR
- VERB 37 ENTR 00 ENTR
- VERB 37 ENTR 06 ENTR
- VERB 37 ENTR 22 ENTR
  (from Options 0 and 4)
- VERB 37 ENTR 23 ENTR
  (from Options 0 and 4)
- VERB 37 ENTR 24 ENTR
  (from Options 0 and 4)
- VERB 34 ENTR in response to the following P20 displays—

  FL VERB 04 NOUN 06 (R1 = 00024)
  FL VERB 06 NOUN 78
  FL VERB 06 NOUN 79
  FL VERB 06 NOUN 34
  FL VERB 01 NOUN 70
  FL VERB 06 NOUN 88
  FL VERB 06 NOUN 49
  FL VERB 50 NOUN 18

Figure 4.2.1-1. Initializing Conditions for Starting the Universal Tracking and Rendezvous Program (CMC P20)— (Sheet 1 of 4)

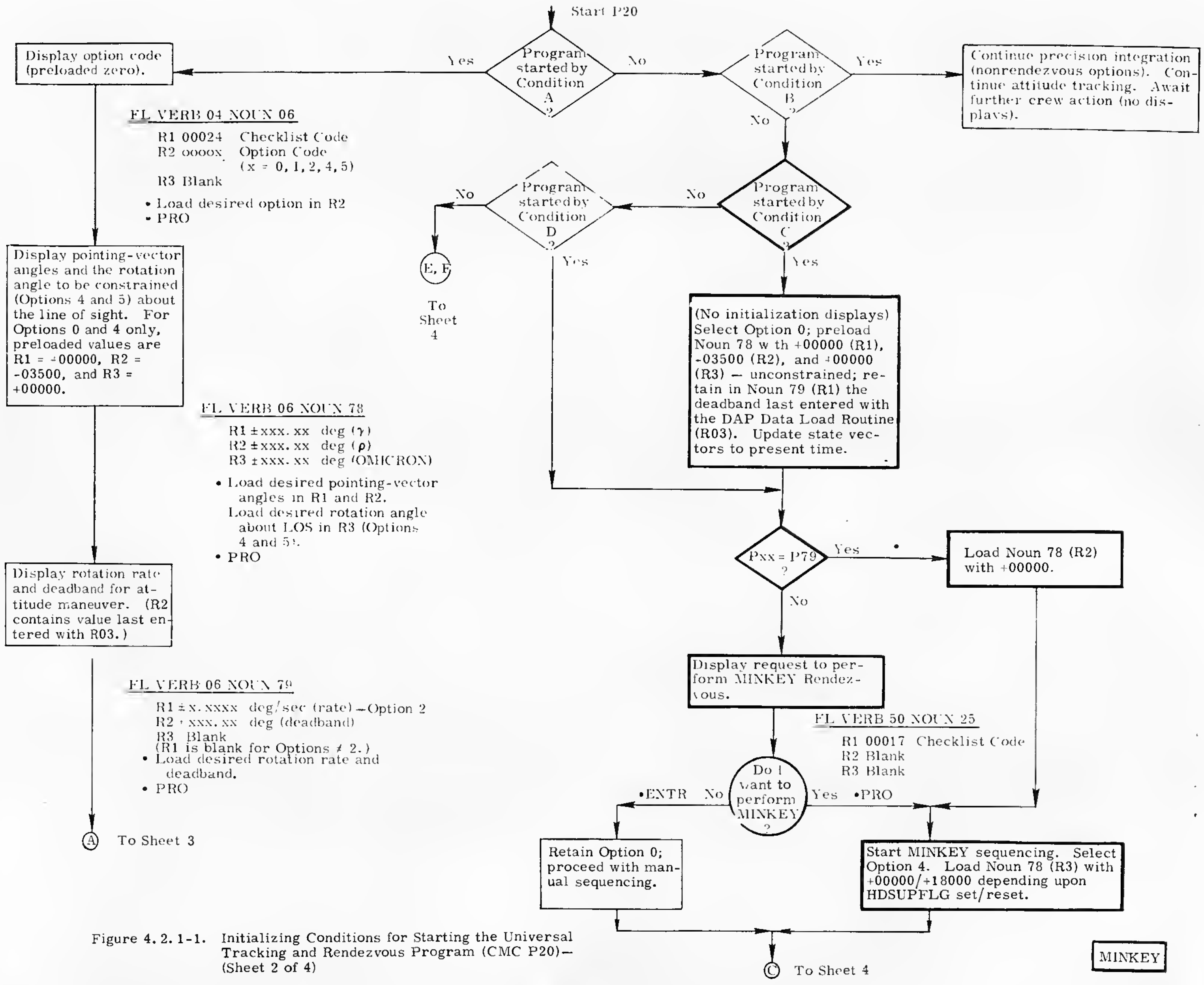


Figure 4.2.1-1. Initializing Conditions for Starting the Universal Tracking and Rendezvous Program (CMC P20)—(Sheet 2 of 4)

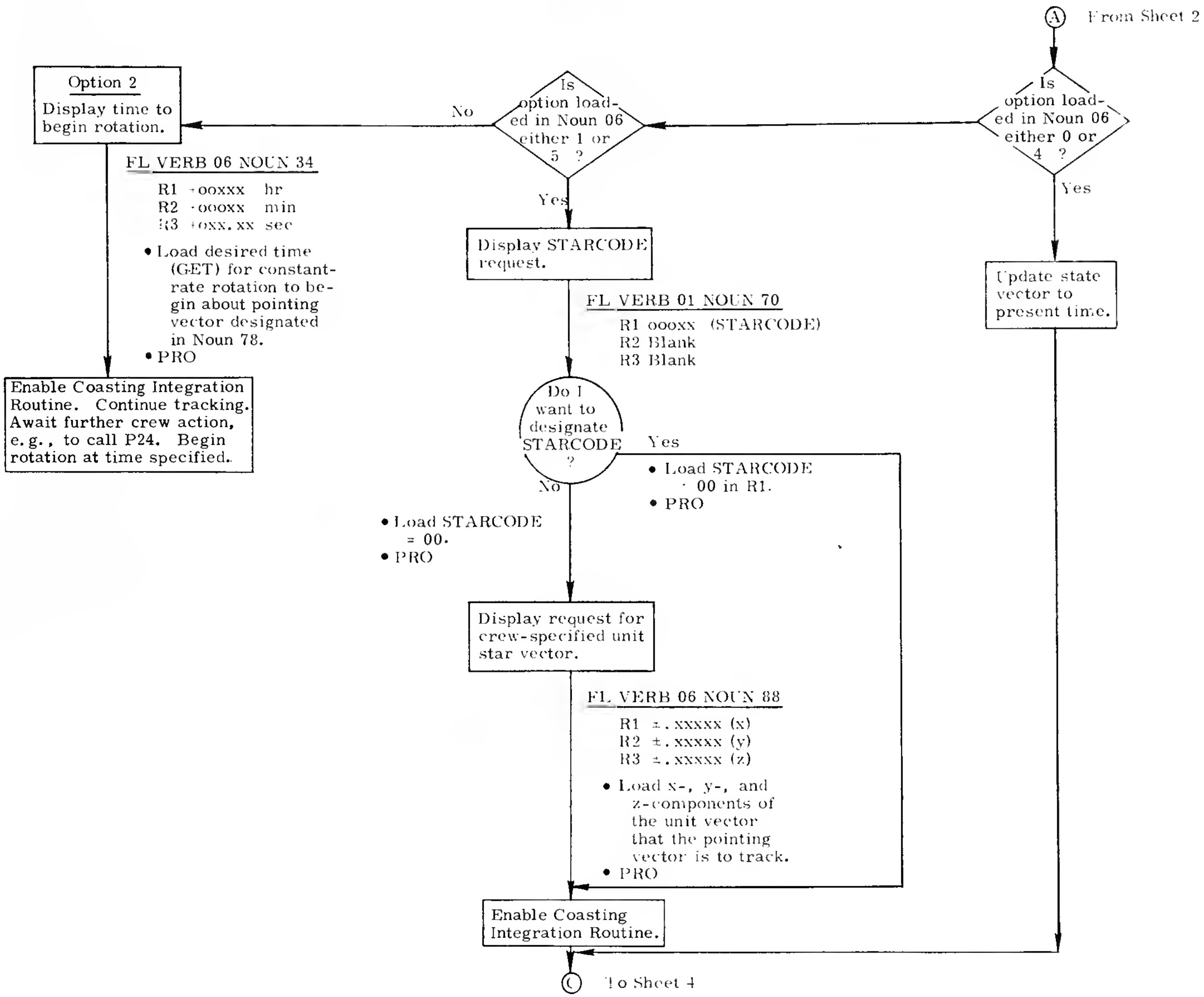


Figure 4.2.1-1. Initializing Conditions for Starting the Universal Tracking and Rendezvous Program (CMC P20)— (Sheet 3 of 4)

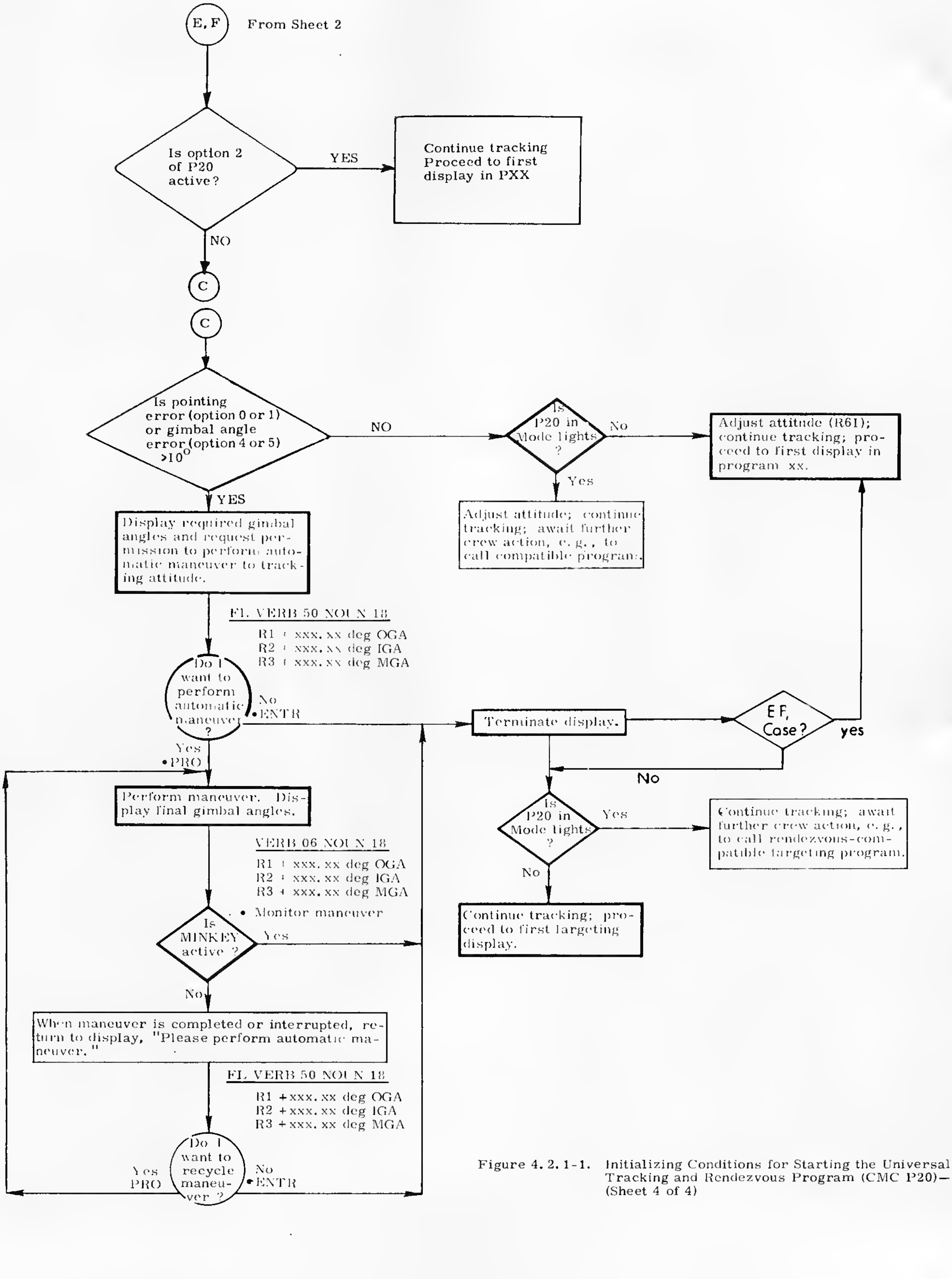


Figure 4. 2. 1-1. Initializing Conditions for Starting the Universal Tracking and Rendezvous Program (CMC P20)—(Sheet 4 of 4)

at a crew-specified celestial body. Once the required attitude has been established, the program continues to track the designated target. The difference between Options 1 and 5 is that Option 1 <u>does not</u> constrain rotation angle about the line of sight, and Option 5 <u>does</u> constrain this angle to a crew-specified value. Option 2 allows the crew to specify a rotation rate, a DAP deadband, and an execution time and have the program initiate a constant-rate rotation about a specified spacecraft vector.

4.2.1.1.1 <u>Procedures (Options 1 and 5).</u>—To specify a spacecraft pointing vector and initiate tracking of a celestial body, proceed as follows:

1. • Key VERB 37 ENTR 20 ENTR
   • Observe flashing display of option code (zero preloaded):

   <u>FL VERB 04 NOUN 06</u>

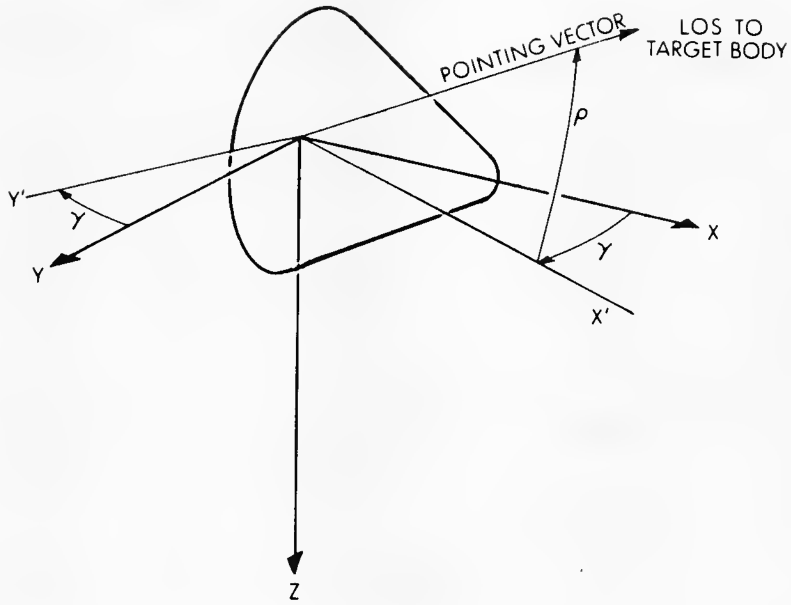
R1	00024	Checklist Code
R2	0000x	Option Code (x = 0,1,2,4,5)
R3	Blank	

2. • Load R2 with 00001 or 00005
   • PRO
   • Observe flashing request for crew to load pointing-vector angles (not preset for these options):

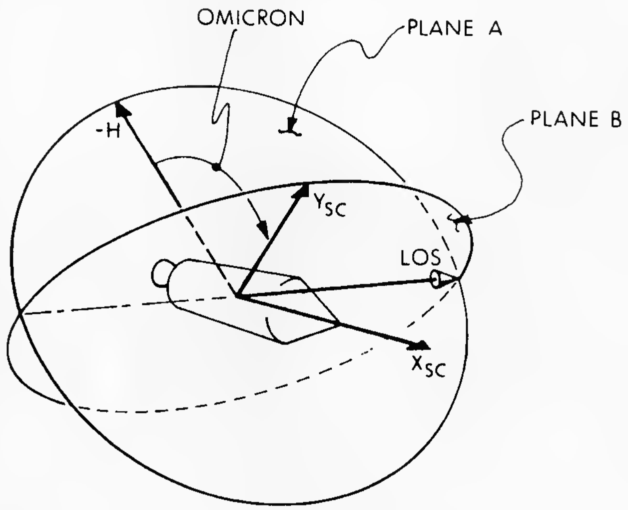
   <u>FL VERB 06 NOUN 78</u>

R1	±xxx.xx	deg (ν)
R2	±xxx.xx	deg (ρ)
R3	±xxx.xx	deg (OMICRON)—not relevant in Option 1

   where ν is positive rotation from the spacecraft +X-axis about the spacecraft Z-axis ($0 \leq \nu < 360$ deg); ρ is positive rotation about the Y'-axis produced in the XY plane by the initial (ν) rotation ($-90 \leq \rho \leq 90$ deg); and OMICRON is the amount of spacecraft rotation about the LOS.



OMICRON is measured as the positive-sense angle between planes A and B: plane A is defined by the negative momentum vector (-H) and the line of sight (LOS); plane B is defined by spacecraft +Y-axis and the LOS.



OMICRON is relevant only to Options 4 and 5; in these options, alignment of the LOS with either the spacecraft Y-axis or the momentum vector is proscribed since the necessary two-plane condition for specifying OMICRON would not exist.

3. • Load NOUN 78 with the desired pointing-vector angles
   • PRO
   • Observe flashing display of deadband:

   FL VERB 06 NOUN 79

   R1 Blank
   R2 +xxx.xx deg (deadband)
   R3 Blank

   (R2 preloaded with last R03 deadband)

4. • Load NOUN 79 with the desired deadband—minimum deadband (0.5 deg) used when register contains zero
   • PRO
   • Observe flashing display of STARCODE:

   FL VERB 01 NOUN 70

   R1 000xx (xx = STARCODE)
   R2 Blank
   R3 Blank

   where legal values of xx are $00 \leq xx \leq 50_8$.

5. • Load R1 of NOUN 70 with the desired STARCODE

   NOTE.—If no STARCODE exists for the body selected for tracking, load R1 of NOUN 70 with 00, key PRO, and observe flashing request for the crew to load the desired unit star vector:

   FL VERB 06 NOUN 88
   (occurs only if R1 of NOUN 70 contains 00000)

   R1 ±.xxxxx (X)
   R2 ±.xxxxx (Y)
   R3 ±.xxxxx (Z)

   Load the desired unit star vector.

· PRO

· Observe flashing request to "Please perform automatic maneuver to tracking attitude" (due to a pointing error greater than 10 deg for option 1 or a gimbal angle error greater than 10 deg for option 5):

FL VERB 50 NOUN 18

R1 +xxx.xx deg OGA
R2 +xxx.xx deg IGA
R3 +xxx.xx deg MGA

NOTE.—If in Option 5, possible Alarm 00401 ("Desired gimbal angles produce gimbal lock"), key VERB 23 NOUN 78 ENTR; change contents of R3 (OMICRON); then key ENTR to deny request for maneuver (reset V50N18FL). When UPLINK ACTY light illuminates (any gimbal-angle error >10 deg), key VERB 58 ENTR (to set V50N18FL). Flashing VERB 50 NOUN 18 returns with a request to perform maneuver to attitude reflecting new OMICRON.

6. · To execute maneuver, key PRO

· Observe nonflashing display of final gimbal angles as automatic maneuver is being performed:

VERB 06 NOUN 18

R1 +xxx.xx deg OGA
R2 +xxx.xx deg IGA
R3 +xxx.xx deg MGA

7. Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually, then key VERB 58 ENTR to reset STIKFLAG.

NOTE 1.—A middle-gimbal angle of ±75 deg during the maneuver causes the RCS DAP to terminate the maneuver and to maintain attitude hold (sets STIKFLAG and zeros HOLDFLAG). Maneuver rate will be as prescribed by R03. When maneuver has completed or is interrupted, the flashing request to perform automatic maneuver (VERB 50 NOUN 18) returns. PRO recycles the maneuver; ENTR causes the Attitude Maneuver Routine (R60) to exit. The Tracking-attitude Routine (R61) continues to track the celestial body. If tracking is interrupted (e.g., by the crew's use of

the RHC) or if the pointing vector is changed (NOUN 78) such that a pointing error (Option 1) or any gimbal-angle error (Option 5) >10 deg results, the UPLINK ACTY light will illuminate signaling the need to perform an R60 maneuver. To initiate R60, key VERB 58 ENTR and respond to flashing VERB 50 NOUN 18 as in steps 6 and 7.

NOTE 2.—In Option 1, the pointing error is measured as the angle between the LOS and the center of the DAP deadband.

4.2.1.1.2 Procedures (Option 2).—To have P20 initiate and maintain a constant-rate rotation about a specified spacecraft vector, proceed as follows:

1. • Key VERB 37 ENTR 20 ENTR
   • Observe flashing display of option code (zero preloaded):

   FL VERB 04 NOUN 06

R1	00024	Checklist Code
R2	0000x	Option Code (x = 0,1,2,4,5)

2. • Load R2 with 00002
   • PRO
   • Observe flashing request for crew to load pointing-vector angles (in Option 2, the vector—not preset—about which the constant-rate rotation shall be established):

   FL VERB 06 NOUN 78

R1	±xxx.xx	deg (ν)
R2	±xxx.xx	deg (ρ)
R3	±xxx.xx	deg (OMICRON)

3. • Load registers R1 and R2 with the desired angles. (OMICRON is not relevant to Option 2.)
   • PRO
   • Observe flashing display of rotation rate and deadband:

FL VERB 06 NOUN 79

R1 ±x.xxxx deg/sec (rate)
R2 +xxx.xx deg (deadband)
R3 Blank

(R2 preloaded with last R03 deadband.)

4. • Load NOUN 79 with desired parameters—minimum deadband (0.5 deg) used when register R2 contains zero
   • PRO
   • Observe flashing display of the time to begin rotation:

FL VERB 06 NOUN 34

R1 +ooxxx hr GET
R2 +oooxx min
R3 +oxx.xx sec

5. • Load NOUN 34 with the desired time (GET) to initiate rotation
   • PRO

NOTE.—If the time loaded is in the past, rotation begins immediately. Otherwise, rotation about the vector specified in NOUN 78 begins at the time specified in NOUN 34. (Option-2-compatible program active, with no intervening "permanent" termination of P20. Refer to Figure 4.2.1-1.) Once rotation begins, the program does not look at the contents of NOUNS 78 and 79 again until rotation is interrupted and restarted. Consequently, to change the rotation axis, rate, or deadband, the crew should effect one of the following:

a. Load new parameters into NOUN 78 and 79; remove the RHC from detent (to stop rotation), then return the RHC to detent and key VERB 58 ENTR to resume rotation using the new parameters.
b. Key VERB 37 ENTR 20 ENTR (with 20 in the PROG lights) and reinitialize with new parameters.
c. Load new parameters; call a program that is incompatible with P20 Option 2 (see Table 4.2.1-I) —rotation stops; then recall a compatible program—rotation resumes with new parameters.

4.2.1.2 P20 Rendezvous Navigation

The rendezvous-navigation mode—Options 0 and 4 of the Universal Tracking and Rendezvous Navigation Program (P20)—is an onboard means of updating either of two state vectors (CSM or LM) carried in the Command Module Computer. The designated state vector is updated by incorporating measurements of line of sight (optics) and range (VHF) from the CSM to the LM. Except during the thrusting phases, P20 operates continuously throughout CSM-LM rendezvous, in conjunction with whichever is appropriate of the following targeting programs:

CSM Active	CSM-targeted LM Maneuvers
P30— External Δv	P72— LM Coelliptic Sequence Initiation
P31— Height Adjustment Maneuver (HAM)	P73— LM Constant Delta Height
P32— Co-elleptic Sequence Initiation (CSI)	P74— LM Transfer Phase Initiation
P33— Constant Delta Altitude (CDH)	P75— LM Transfer Phase Midcourse
P34— Transfer Phase Initiation (TPI)	
P35— Transfer Phase Midcourse (TPM)	
P36— Plane Change (PC)	

In addition, P20 performs X-axis tracking (if R1 of Noun 78=0) when initiated by the Rendezvous Final Program (P79). Traditionally, rendezvous is effected using the concentric flight plan discussed in the Introduction to Targeting Programs (subsection 5.1). The rendezvous GNCS functional requirements are Navigation, Targeting, Powered-flight Control and Guidance, and IMU Alignment.

a. Navigation.—Optical and VHF ranging data are continually incorporated to improve the estimate of the inertial position and velocity of the two vehicles. This function is controlled by the rendezvous-navigation mode of P20, which is described in this section (paragraph 4.2.1.2). LGC rendezvous navigation is described in paragraph 4.3.1. The rendezvous-navigation mode also controls the spacecraft orientation during the coasting phase of rendezvous.

b. Targeting.—On the basis of the command-module computer (CMC) estimate of inertial position and velocity, a required change in velocity is computed for each thrusting maneuver. This function is performed by the targeting programs described in Section 5.0.

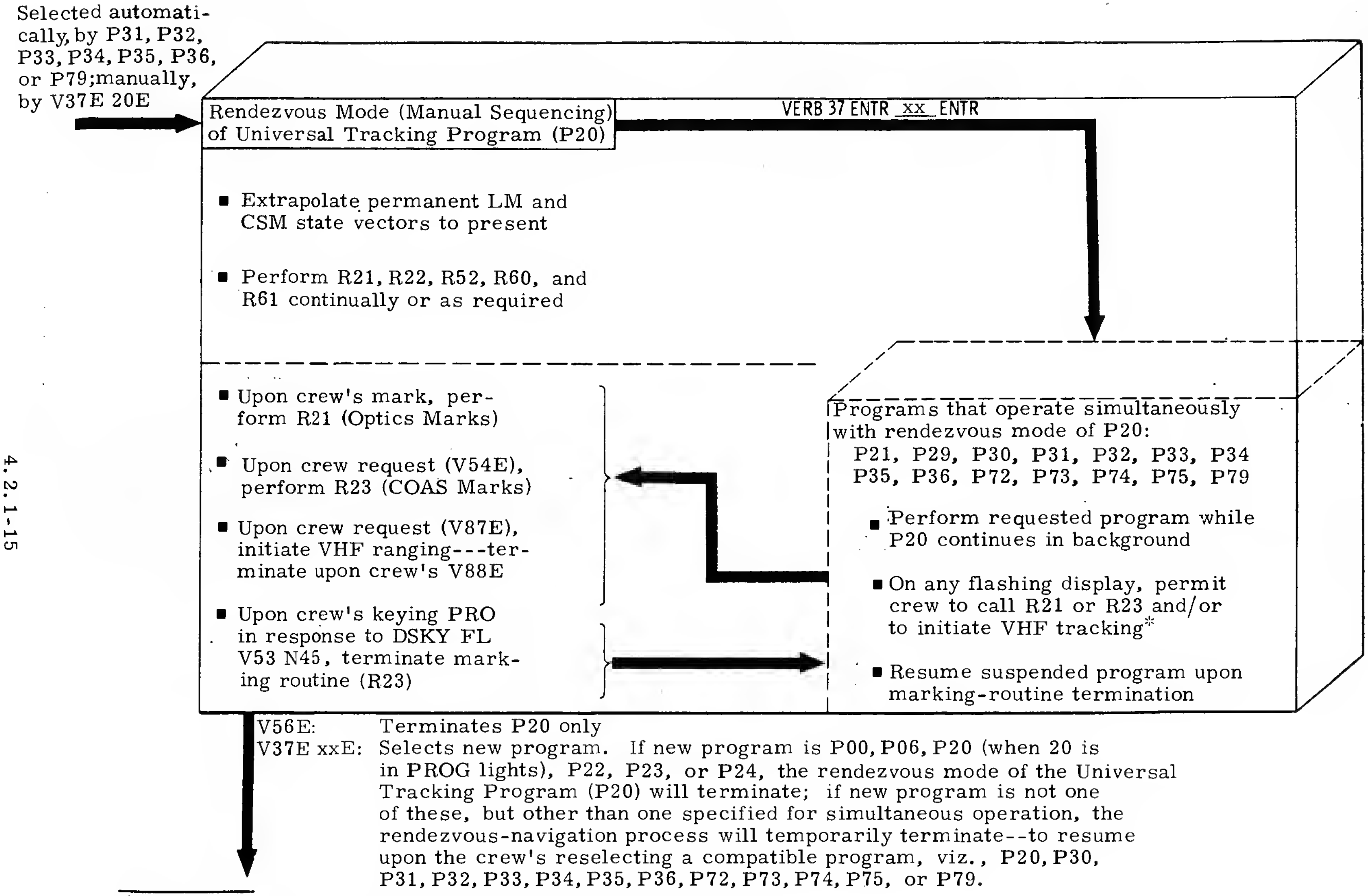
c. Powered-flight Control and Guidance.—On the basis of targeting data and crew inputs, the CMC controls the reaction-control-system (RCS) and service-propulsion-system (SPS) thrusting maneuvers required for rendezvous. The powered-flight programs are discussed in Section 6.0.

d. IMU Alignment.—In addition to its knowledge of the inertial state vectors of the two vehicles, the CMC must know the spacecraft's orientation. Programs for aligning and determining the orientation of the inertial measurement unit (IMU) are described in Section 7.0.

The following discussion—through paragraph 4.2.1.2.5—applies to rendezvous navigation in general, using manual sequencing. Paragraph 4.2.1.2.6 describes rendezvous navigation using minimum-keystroke (MINKEY) sequencing.

Operating in the background throughout rendezvous, P20 becomes temporarily dormant (attitude tracking continues) upon the crew's requesting a final targeting computation, remains dormant (no tracking) during the powered-flight phase, and re-awakens only upon the crew's selecting a compatible targeting program (Figure 4.2.1-2) or P20—VERB 37 ENTR 20 ENTR. Should it become necessary to call any other program except P00, P06, P22, P23, or P24 (e.g., IMU Alignment, P52), Rendezvous Navigation will similarly cease until P20 or a compatible targeting program is re-selected. Rendezvous Navigation, then, operates in conjunction with its complementary targeting programs (P30, P31, P32, P33, P34, P35, P36, P72, P73, P74 and P75) or with P79. Once P20 is entered, subsequent selection of a compatible targeting program or of P79 changes the DSKY PROG number to reflect the program selected, but allows navigation to continue.

Accordingly, the crew can, upon a flashing display during a P20-compatible program (normally flashing VERB 16 NOUN 45), take the required optical measurements simply by depressing the mark button. If necessary, the crew can call the Backup Rendezvous Tracking Sighting Mark Routine (R23—VERB 54 ENTR), take the required optical measurements, and, by depressing the PRO key, return to the point departed from in the major program in progress. Similarly, the crew can call for VHF range data to be incorporated by selecting VERB 87 ENTR, which will allow range data to be incorporated until the crew resets the VHF RANGE flag by keying VERB 88 ENTR. (See paragraph 4.2.1.2.6 for MINKEY procedure.) For marks to be incorporated, the UPDATE flag must be set. The flag is automatically reset



*Navigation data are not incorporated, however, during the time that UPDATE flag is reset. See paragraph 4.2.1.2.

Figure 4.2.1-2. Simplified Flow Diagram Showing Relationship of P20 Rendezvous Mode (Manual Sequencing) to Other CMC Programs

during prethrust computations in order to protect erasable memory. The essential concern to the crew is that, with the following exceptions, marks can be incorporated during targeting-program displays preceding the request for final targeting computation (PRO response to flashing VERB 16 NOUN 45—temporarily terminates navigation): marks not incorporated during (a) P79, (b) recycle displays preceding the VERB 06 NOUN 81 display in P34/P74, (c) alarm displays, (d) displays after the first two in P30. (See Section 5.0.) Essentially, P20 provides the targeting programs with a continually updated state vector for one vehicle and the current state vector for the other vehicle. The appropriate targeting program, in turn, computes the Δv required to effect rendezvous.

Figure 4.2.1-3 is a simplified functional diagram of the logic for updating one of the two CMC state vectors—designated in Figure 4.2.1-3 as "passive vehicle orbit" and "active vehicle orbit."

Extrapolating both state vectors to the time of measurement, P20 computes an estimated tracking quantity ($\hat{Q}$), which is compared with a measured tracking quantity (Q) to obtain a measurement deviation δQ. This is multiplied by a statistical weighting vector ($\underline{\omega}$) comprising an onboard computation of expected state-vector uncertainties, expected sensor performance ($\overline{\alpha^2}$), and the sensor geometry vector ($\underline{b}$). The resulting $\delta \underline{x}$ is a statistically optimum linear estimate of the state deviation to be added to the current estimate of the state vector selected to be updated.

Typically, tracking data are processed once every minute for VHF marks and as often as every 20 sec for optics; the selected state vector is automatically updated by the computed deviation $\delta \underline{x}$. If the magnitude of either the position-vector change ($\delta \underline{r}$) or the velocity-vector change ($\delta \underline{v}$) of the deviation $\delta \underline{x}$ is not less than preset values, however, the crew is alerted by a special display, and the update occurs only upon crew command, after verifying the tracking data.

4.2.1.2.1 Crew Options.—Before selecting the rendezvous mode of P20, the crew should resolve the following questions:

1. Which attitude option (0 or 4) do I wish to select? (Options listed in Table 4.2.1-I.)
2. If option 4 is to be used, what kind of sequencing do I want—manual or MINKEY?

If option 0 is desired (unconstrained attitude about pointing vector), the crew has no choice but to use manual sequencing, since MINKEY can only be performed using

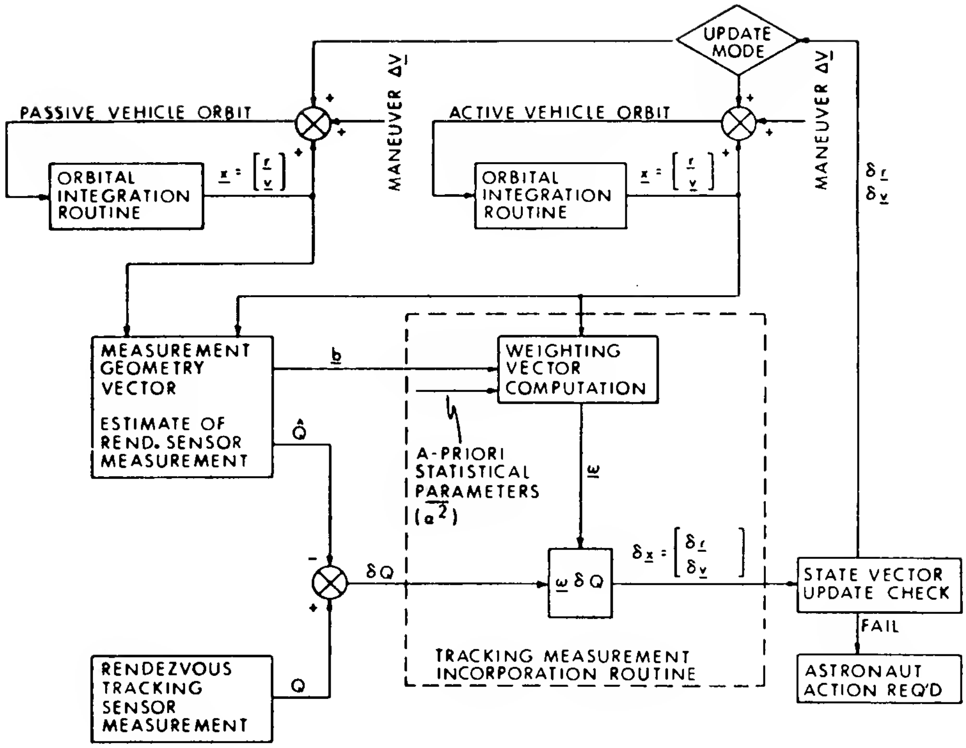


Figure 4.2.1-3. Simplified Rendezvous Navigation Diagram (CSM)

option 4 (attitude constrained about pointing vector). If option 4 is desired, however, the crew has the further option of either using manual or MINKEY sequencing. For MINKEY sequencing, the crew would start the rendezvous mode of P20 simply by keying in a MINKEY-compatible targeting program (P31, P32, P33, P34, P35, P36, P79). Program sequencing would then be as described in paragraph 4.2.1.2.6. For manual sequencing under option 0, the rendezvous mode of P20 is also started by calling a compatible targeting program, as described in paragraph 4.2.1.2.2. In either instance, manual or MINKEY, the P20 rendezvous mode can be entered by keying VERB 37 ENTR 20 ENTR and proceeding through the universal-tracking initialization displays. This entry is mandatory, however, when manual-sequencing option 4 is desired. The procedure for selecting this configuration is as follows:

1. Key VERB 37 ENTR 20 ENTR and observe preloaded option display:

   <u>FL VERB 04 NOUN 06</u>

R1	00024	Option Code
R2	00000	Preloaded zero option
R3	Blank	

2. Key VERB 22 ENTR 4 ENTR.
3. When satisfied with NOUN 06 option, key PRO and observe preloaded tracking attitude:

   <u>FL VERB 06 NOUN 78</u>

R1	+000.00	deg	γ
R2	-035.00	deg	ρ
R3	+000.00	deg	OMICRON

   (where γ, ρ, and OMICRON are as defined in paragraph 4.2.1.1.)

4. To change NOUN 78 values, key VERB 2x and load the appropriate register(s).
5. When satisfied with NOUN 78 values, key PRO and observe R03-loaded DAP deadband.

FL VERB 06 NOUN 79

R1	Blank		
R2	+xxx.xx	deg	Deadband
R3	Blank		

6. To change deadband, key VERB 22 ENTR and load register R2 with the desired value—minimum deadband (0.5 deg) used when register contains zero.

7. When satisfied with NOUN 79 values, key PRO and observe R60 request to perform automatic attitude maneuver to the displayed gimbal angles (if required change to any gimbal angle is >10 deg).

FL VERB 50 NOUN 18

R1	+xxx.xx	deg	OGA
R2	+xxx.xx	deg	IGA
R3	+xxx.xx	deg	MGA

8. To perform automatic maneuver, key PRO and observe nonflashing display of final gimbal angles as the maneuver is being performed; monitor FDAI Ball and Attitude Error Needles.
9. When attitude maneuver has completed and the flashing VERB 50 NOUN 18 returns, key PRO to recycle, ENTR to exit R60.
10. Take marks at crew's discretion; when ready for targeting program, key VERB 37 ENTR 3x ENTR and observe request to perform MINKEY Rendezvous.

FL VERB 50 NOUN 25

R1	00017	Checklist Code
R2	Blank	
R3	Blank	

11. To perform manual sequencing, key ENTR and observe first targeting display (assuming no attitude change). All initialization values will be retained.*

*A PRO response to the VERB 50 NOUN 25 display calls MINKEY. In that instance, the contents of NOUNS 78 and 79 will be conserved. If Option 4 not previously selected, however, that option would now be selected automatically and N78 (R3) would be loaded as determined by HDSUPFLG.

NOTE.—As when P20 is entered from a targeting program, NOUNS 78 and 79 can be called and their contents changed whenever a change is required. Also, as with a targeting-program entry to P20, the crew's changing the contents of NOUN 06 will have no effect once he keys PRO on the initial display.

4.2.1.2.2 Manual Sequencing of Rendezvous Navigation.—

4.2.1.2.2.1 Functional Description.—The following routines used by P20 in the rendezvous navigation mode.

R02 — The IMU Status Check Routine is called by programs requiring an aligned IMU. R02 checks the IMU orientation (REFSMMAT) flag and (if not set) checks the IMU operate bit. A PROG alarm is initiated if either is not set. The crew verifies the alarm by keying VERB 05 NOUN 09 ENTR. If IMU orientation is not known, but the inertial subsystem (ISS) is operating, alarm code 00220 will be displayed; if the ISS is not operating, alarm code 00210 will be displayed. For either alarm, the crew keys RSET, and the program goes to the Final Automatic Request Terminate Routine (R00), where the crew turns on the ISS (if off) and calls either the primary or backup IMU Orientation Determination Program (P51 or P53).

R22 — The Rendezvous Tracking Data Processing Routine is started by the P20 rendezvous mode and continues to run until the P20 rendezvous mode is terminated. R22 processes optical and VHF ranging data and updates the state vector designated by the state-vector flag. Incorporation of VHF data is enabled by VERB 87 ENTR and disabled by VERB 88 ENTR. (VHF data are automatically incorporated in the MINKEY sequence. See paragraph 4.2.1.2.6.)

R61 — The Tracking Attitude Routine is called either by P20 or R52. R52 calls R61 on every pass during rendezvous tracking (options 0 and 4). On every fourth pass (only), R61 extrapolates the CSM and LM state vectors to the present, calculates the LOS from the CSM to the LM, and computes the IMU gimbal angles required to keep the CSM properly oriented for tracking the LM. If option 0 has been selected, an appropriate attitude is held for SXT and VHF tracking (as determined by NOUN 78 values—for preferred tracking attitude,

Register R1, 000.00 deg; R2, -035.00 deg).* If option 4 has been selected, the attitude will be further constrained by the contents of NOUN 78, Register R3, e.g., 000.00 deg (heads-up) or 180.00 deg (heads-down). Comparing the spacecraft pointing axis (center of DAP deadband) with the LOS (Option 0), or comparing the required and present gimbal angles in each axis (Option 4), R61 determines whether any error exceeds 10 deg. If not, R61 computes the LOS angular velocity, resolves it into RCS control axes, and generates appropriate input to the RCS DAP. If, on the first pass through R61, with V50N18FL flag set, the error exceeds 10 deg, R61 calls the Attitude Maneuver Routine (R60). If, on subsequent passes through R61 (V50N18FL flag reset), the pointing error (Option 0) or a gimbal-angle error (Option 4) exceeds 10 deg, R61 turns on the UPLINK ACTY light but does not call R60. Should the astronaut wish an R60 maneuver performed, he would key VERB 58 ENTR, setting the V50N18FL flag (and resetting STIKFLAG) and instructing R61 to call R60.

After commanding the maneuver or providing the appropriate RCS DAP input, R61 returns to the calling program.

R60 — The Attitude Maneuver Routine maneuvers the spacecraft to an attitude specified by the calling program. The astronaut can choose to perform the maneuver manually or automatically. If manually, the maneuver is performed with the rotational hand controller (RHC) while the astronaut monitors the FDAI; if automatically, the maneuver is performed by CMC-commanded RCS jet firings. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver and to maintain attitude hold (sets STIKFLAG and zeros HOLDFLAG).

> NOTE.—STIKFLAG is also set by the crew's moving the RHC out of detent. To enable subsequent tracking, key VERB 58 ENTR to reset STIKFLAG.

R52 — During rendezvous navigation, the Automatic Optics Positioning Routine keeps the CSM optics pointed at the LM (OPTICS MODE switch in CMC). Calculating the LOS to the LM, with R61 maintaining

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*For COAS, or X-axis, tracking, NOUN 78 values are as follows: Register R1, 000.00 deg; R2, 000.00 deg; R3, as desired.

tracking attitude, R52 drives the optics shaft and trunnion accordingly until the TRACKFLG is reset or the OPTICS MODE switch is set to MAN.

R21 — The Rendezvous Tracking Sighting Mark Routine is called automatically by R22. The crew can take SXT marks anytime during R22 unless R23 has been selected.

R23 — The Backup Rendezvous Tracking Sighting Mark Routine allows the crew to use the crew optical alignment sight (COAS) rather than the sextant (SXT), for rendezvous tracking. R23 is called by the crew's keying VERB 54 ENTR and is terminated by PRO.

4.2.1.2.2.2 Manual-sequencing Procedures.—Table 4.2.1-II is a chronological summary of G&N procedures and displays associated with a manually sequenced rendezvous. Table 4.2.1-III summarizes extended and regular verbs that may be used during rendezvous. An amplified description of the procedures is presented here.

I. INITIALIZATION

A. Perform preliminary set-up of controls, switches, and displays according to mission procedures.

B. Perform DAP Data Load Routine (R03)—paragraph 9.2.1—and load desired deadband and maneuver rate for rendezvous attitude maneuvers. Load other DAP parameters as required by mission procedures and spacecraft configuration.

C. Set up GNCS according to Mission Procedures.

D. If an hour or more has elapsed since the W-matrix was initialized—or if the state vector has not been updated via P27—key VERB 93 ENTR to reinitialize W-matrix.

E. Initiate rendezvous navigation.

1. Key VERB 37 ENTR xx ENTR (where xx is 31, 32, 33, 34, 35, 36). (If xx is 72-75, the program proceeds to first display in Pxx without turning on P20. Selection of P79 will turn on P20 if there is a valid REFSMMAT.) Selection of a rendezvous targeting program causes a check to be made of REFSMMAT. If the IMU is not on and aligned to a known orientation, the program proceeds to the first display (no alarm) in targeting program xx. If there is a valid REFSMMAT, however , P20 is turned on and performs the following:

a. Selects the LM state vector as the one to be updated.

> NOTE.—The crew can change the state vector selected for update by keying VERB 81 ENTR, which designates the CSM state vector for update. VERB 80 ENTR is available for reselecting the LM state vector for update should there be a requirement for doing so. Considerations affecting the decision on which state vector to update are (1) the desire to update the state vector having the largest uncertainties, (2) the desire to update the state vector of the vehicle that is to perform the maneuver. Ordinarily, both considerations favor updating the CMC-resident LM state vector, and that is the preset option. Should large uncertainties develop in the CSM state vector, however, while the CMC's knowledge of the LM's position and velocity remains relatively good, the crew can use VERB 81 to change the preset option.

b. Sets V50N18FL flag enabling R60 and the display of required gimbal angles for a maneuver to the desired tracking attitude.

c. Sets TRACKFLG, enabling automatic attitude maneuver, optics pointing, and state-vector update.

d. Sets UPDATFLG, enabling state-vector update.

e. Sets RNDVZFLG, enabling total rendezvous mode of P20.

f. Resets UTFLAG, terminating nonrendezvous modes of P20.

g. Extrapolates both CMC-resident state vectors (CSM and LM) to the present time.

h. Selects option 0, designating rendezvous-mode tracking with unconstrained rotation about the pointing vector.

> NOTE.—It serves no purpose for the crew to change the NOUN 06 option when the rendezvous mode is initiated by a targeting program. See crew options, paragraph 4.2.1.2.1.

i. Loads NOUN 78 with γ = 000.00 deg (R1); ν = -035.00 deg (R2); and OMICRON = 000.00 deg (R3, unconstrained).

j. Loads NOUN 79 with deadband (R2, xxx.xx deg) last designated by Routine R03.

NOTE.—NOUNS 78 and 79 are not displayed when the rendezvous mode is initiated by a targeting program. If the crew wishes to change the contents of either noun, he can do so by keying (a) VERB 2x, (b) the appropriate noun, (c) ENTR, (d) the desired value(s), (e) ENTR. Subsequent tracking will conform to the new inputs.

k. Flashes VERB 50 NOUN 25 (R1, 00017), "Please perform MINKEY Rendezvous."

2. To perform manually sequenced rendezvous, key ENTR. (To perform MINKEY-sequenced rendezvous, key PRO and proceed as described in paragraph 4.2.1.2.6.) The crew's ENTR on the flashing VERB 50 NOUN 25 display causes the pre-selected option and all initialized values in NOUNs 78 and 79 to be retained and initiates the required tracking-attitude maneuver (R61/R60). If a maneuver of 10 deg or less is required, it is accomplished by R61. If a maneuver greater than 10 deg is required, R61 calls R60 (V50N18FL flag set), which displays the required gimbal angles and requests the crew to perform an automatic tracking-attitude maneuver:

FL VERB 50 NOUN 18

R1	+xxx.xx	deg	OGA (Roll)
R2	+xxx.xx	deg	IGA (Pitch)
R3	+xxx.xx	deg	MGA (Yaw)

3. To accept the automatic maneuver, set the SC CONT switch to CMC, the CMC MODE switch to AUTO, and key PRO. (To perform the maneuver manually, key VERB 62 ENTR for FDAI display of total attitude error and use the RHC to null the needles.) While the automatic maneuver is in progress, a nonflashing VERB 06 NOUN 18 displays required gimbal angles. The crew monitors the maneuver on the FDAI ball and the attitude-error needles. If the maneuver approaches gimbal lock, the crew uses the RHC to complete the maneuver manually.

NOTE.—A middle-gimbal angle of ±75 deg causes the RCS DAP to terminate the automatic maneuver and to maintain attitude hold. The maneuver must be completed with the RHC, referencing the FDAI ball to avoid gimbal lock. After using the RHC to complete the maneuver, the crew must key VERB 58 ENTR to reset STIKFLAG and allow subsequent automatic maneuvers.

When the maneuver has completed, the flashing VERB 50 NOUN 18 returns. To trim out residual errors, the crew can recycle the maneuver by keying PRO again, or he can use the RHC to make final attitude adjustments (rotation about the pointing vector, for example). Again, use of the RHC must be followed by VERB 58 ENTR to reset STIKFLAG.

4. When satisfied with the tracking attitude, key ENTR. This terminates R60, starts the Automatic Optics Positioning Routine (R52), and calls up the first display in targeting program xx. (See Section 5.0 for a discussion of targeting-program procedures.) R61 continues to compute and maintain a tracking attitude appropriate for the designated option and pointing vector.

NOTE.—If on subsequent passes through R61 (V50N18FL flag reset), the difference between the DAP deadband center and the LOS is found to be greater than 10 deg, the program will illuminate the UPLINK ACTY light but will not allow R61 to call R60. If maneuver is desired, the crew must key VERB 58 ENTR. R60 will then be called, and the crew will be presented a request to perform an automatic maneuver to tracking attitude (flashing VERB 50 NOUN 18)—as in step 2.

5. For automatic optics positioning, set the OPTICS ZERO switch to OFF and the OPTICS MODE switch to CMC. The Automatic Optics Positioning Routine (R52) will (a) extrapolate the CSM and LM state vectors to the present time plus 2.4 seconds, (b) get the CSM attitude from the ICDUs, (c) compute a vector from the CSM to the LM, (d) calculate the required optics shaft and trunnion angles, and (e) drive the OCDUs to point the sextant line of sight at the LM.

NOTE.—If the required trunnion angle is greater than 50 deg, R52 will drive the OCDUs to the trunnion upper limit (~50 deg). The crew should verify that the CSM is at the proper tracking attitude. (The desired gimbal angles can be observed by keying VERB 16 NOUN 22 ENTR (or on the FDAI Error Needles—Mode II), the desired optics angles by keying VERB 16 NOUN 92 ENTR.) If an attitude correction is necessary, the crew can do one of the following: (a) use the RHC to manually maneuver the spacecraft to the desired gimbal angles; (b) verify that the SC CONT switch is in CMC, the CMC MODE switch is in AUTO, and that the correct attitude parameters are loaded in NOUN 78—then key VERB 58 ENTR (sets V50N18FL flag and resets STIKFLAG) to allow R61 to call R60 to perform the required maneuver.

II. RENDEZVOUS TRACKING, NAVIGATION, AND TARGETING

The initialization phase of the rendezvous-navigation mode ends when the crew is satisfied with the tracking-attitude parameters contained in NOUNs 78 and 79, has the tracking attitude established, and is ready to proceed with navigation and targeting. From this point until the crew requests a final targeting solution, he must coordinate his navigation activities with the targeting program in progress. Tracking and W-matrix-reinitialization schedules are discussed in paragraph 4.2.1.2.5. Targeting programs are described in Section 5.0.

A. VHF TRACKING

When the tracking attitude has been established, key VERB 87 ENTR to initiate VHF tracking. VHF range data will then continue to accumulate at approximately 1-minute intervals until terminated by the crew's keying VERB 88 ENTR or VERB 37 ENTR xx ENTR. Incorporation of the data will cease, automatically (UPDATFLG reset), when the crew requests a final targeting solution (PRO on flashing VERB 16 NOUN 45). (See Restrictions and Limitations, paragraph 4.2.1.2.4.)

B. OPTICS TRACKING (SXT OR SCT)

Take optical line-of-sight measurements on the LM according to a predetermined tracking schedule. (See Tracking and W-Matrix-reinitialization Schedules, paragraph 4.2.1.2.5.):

1. Set OPTICS MODE switch to MAN.
2. Use optics hand controller (OHC) to center LM in SXT.

3. Depress MARK button.
4. If mark was satisfactory, wait the prescribed time (based on geometry, timeline, etc.), recenter the LM in the SXT, and repeat the mark (if more marks are desired). If mark was unsatisfactory, depress MARK REJ button, within 15 sec, and repeat mark procedure.

> NOTE.—Marks are processed by the Rendezvous Tracking Data Processing Routine (R22). If any mark results in an excessive update (discussed in paragraph 4.2.1.2.5.1), a priority display (flashing VERB 06 NOUN 49) will automatically interrupt any program-initiated display and present the magnitude of the excessive update:

<u>FL VERB 06 NOUN 49</u>

R1	+xxx.xx	n. mi.	ΔR
R2	+xxxx.x	ft/sec	Δv
R3	ooooox	Source Code	
	(1 = optics, 2 = VHF ranging)		

After 2 seconds (priority display), key PRO to incorporate the data; key VERB 32 ENTR to reject the data.

C. BACKUP (COAS) TRACKING

To perform sighting marks using the backup (COAS) optics, proceed as follows:

1. Load NOUN 78 Registers R1 and R2 with +000.00 deg (X-axis tracking).
2. Key VERB 58 ENTR (if necessary) to set V50N18FL flag, reset STIKFLAG, and cause R61 to call R60 to perform maneuver to X-axis tracking attitude. (Refer to initialization procedures for initiating rendezvous navigation.)
3. When satisfied with tracking attitude, key VERB 54 ENTR to call the Backup Rendezvous Tracking Sighting Mark Routine (R23).

<u>FL VERB 06 NOUN 94</u>

R1	xxx.xx	deg	SA (X-axis nominal = +00000)
R2	xx.xxx	deg	TA (X-axis nominal = +57470)

4. Load quivalent shaft angle (SA) and equivalent trunnion angle (TA) for the alternate LOS in NAVBASE coordinates.

   NOTE.—In-flight calibration of COAS should be performed (as described in paragraphs 7.2.2 and 7.2.3) before use with rendezvous. If the primary optics (SXT or SCT) are optically functional but unusable in their shaft-and-trunnion drive function, they can be used as the backup optical device by loading NOUN 94 with the frozen shaft and trunnion angles (from the telescope precision angle counter—TPAC—or NOUN 91) and by loading the equivalent LOS values into NOUN 78.

5. When satisfied with NOUN 94 values, key PRO and observe request to perform alternate LOS mark:

   FL VERB 53 NOUN 45

R1	+xxBxx	VHF-Optics marks
R2	±xxBxx	min-sec TFI
R3	-00001 or xxx.xx	deg MGA

   NOTE.—Registers R2 and R3 are only valid when calculated by a targeting program. Register R1 contains number of marks processed by R22. Left two digits display VHF marks; right two digits display optics marks.

6. When called for by tracking schedule, take COAS marks as follows:
   a. Use RHC to center LM in COAS.
   b. To mark, key ENTR.
   c. To reject mark (within approximately 15 seconds), key VERB 86 ENTR and repeat a and b.
   d. To accept mark, wait the prescribed time (based on geometry, time line, etc.), recenter LM in COAS, and repeat the mark (if more marks are desired).
   e. To exit R23 and return to targeting display, key PRO.

NOTE.—Marks are processed by the Rendezvous Tracking Data Processing Routine (R22). If any mark results in an excessive update (discussed in paragraph 4.2.1.2.5.1), a priority display (flashing VERB 06 NOUN 49) will automatically interrupt any program-initiated display and present the magnitude of the excessive update:

FL VERB 06 NOUN 49

R1	+xxx.xx	n. mi.	ΔR
R2	+xxxx.x	ft/sec	Δv
R3	oooox	Source Code (1 = optics, 2 = VHF ranging)	

After 2 seconds (Priority display), key PRO to incorporate the data; key VERB 32 ENTR to reject the data.

D. CHANGE W-MATRIX (V67E)

1. To change the preset RMS error values, key VERB 67 ENTR and load the desired values in registers R1 and R2 of NOUN 99:

FL VERB 06 NOUN 99

R1	+xxxxx.	ft (position error)
R2	+xxxx.x	ft/sec (velocity error)
R3	+00001	Option Code (Rendezvous)

2. When desired values have been loaded (R3 must contain 00001 for rendezvous), key PRO to exit Extended VERB 67.

NOTE.—VERB 93 ENTR is required for initializing to the new NOUN 99 values.

E. W-MATRIX REINITIALIZATION (V93E)

To reinitialize W-matrix to preset RMS position and velocity errors, key VERB 93 ENTR. (W-matrix-reinitialization schedules and strategies are discussed in paragraph 4.2.1.2.5.)

III. PLANE-CHANGE IMU ALIGNMENT

When a plane-change maneuver is to be performed that requires rotating the CSM's X-axis normal to the orbital plane, the maneuver must be preceded by an IMU realignment. The MINKEY procedure for plane-change IMU realignment is described in paragraph 4.2.1.2.6. The manually sequenced procedure is to call the IMU Realign Program (P52, Option 4) immediately after completing the Plane-Change Targeting Program (P36). (Alignment programs are

described in Section 7.0.) To effect the desired alignment, the platform is pulse torqued to a pseudo landing-site orientation that lies approximately 45 degrees out of the orbital plane. After realigning the IMU, the crew calls the Powered-flight Program (P40/P41) to perform the out-of-plane maneuver. When the maneuver has been completed, the crew calls P20 to return the spacecraft to its original (X-axis in-plane) orientation. Then, the crew calls P52 (Option 4) to realign the IMU for the actual in-plane landing site (PRO on flashing VERB 06 NOUN 89).

> NOTE.—The crew calls P52 to realign the IMU after the spacecraft has been returned to its original (X-axis in-plane) attitude. If P52 is performed first, the IMU may be driven into gimbal lock.

IV. RENDEZVOUS THRUSTING

During each rendezvous targeting program, navigation ends when the crew requests a final targeting solution (PRO on the flashing VERB 16 NOUN 45). Typically, depending upon mission procedures and the maneuver to be performed, this request is made 10 to 12 minutes before ignition. After the final targeting solution has been displayed and recorded, the crew calls the appropriate powered-flight program (P40/P41) and either performs the thrusting maneuver (CSM active) or performs backup procedures (LM active). (Powered-flight programs are described in Section 6.0.)

> NOTE.—If the thrusting maneuver involves rotating the spacecraft X-axis normal to the orbital plane, an IMU realignment must be performed before the powered-flight program is called. See Sequence III, above.

After the maneuver (LM active), the crew calls the Target-Δv Program (P76) to change the CMC-resident LM state vector to reflect the LM's change in position and velocity. (The Target-Δv Program is described in paragraph 5.2.11.) After the LM state vector has been changed by P76, or after the thrusting maneuver has been completed (CSM active), the crew calls the next rendezvous-targeting program in the sequence and is again presented with a request to perform MINKEY Rendezvous (flashing VERB 50 NOUN 25, R1 = 00017). If the crew wishes to continue rendezvous with manual sequencing, he keys ENTR and proceeds as in Sequence I,E above. If he wishes to change to MINKEY sequencing, he keys PRO and proceeds as described in paragraph 4.2.1.2.6.

V. FINAL PHASE

When the final rendezvous thrusting maneuver has been performed, the crew has the option either of calling the Rendezvous Final Program (P79) or of manually loading +000.00 deg into Register R2 of NOUN 78 and then reselecting P20. If he elects to call P79, the program will automatically load R2 of NOUN 78 with the +X-axis value and then flash a request to perform a maneuver to the X-axis tracking attitude (flashing VERB 50 NOUN 18).

> NOTE 1.—P79 also selects Option 4. Therefore, the crew should not select P79 if he specifically wants rotation about the pointing vector to be unconstrained.
>
> NOTE 2.—P79 does not reinitialize R1 of NOUN 78 to the nominal zero value. Consequently, if a non-zero value has been manually loaded into this register, it must be manually corrected for P79 operation.
>
> NOTE 3.—If P79 is selected when REFSMMAT flag (REFSMFLG) is zero (reset), the PROG number will appear, but the program will not function.

When the attitude maneuver has been completed, P79 proceeds automatically to the Rendezvous Parameter Display Routine (R31). (See MINKEY Rendezvous, paragraph 4.2.1.2.6.)

Should the crew elect to reselect P20 to perform the maneuver to point the CSM +X-axis at the LM, he would first load Register R2 of NOUN 78 with +000.00 deg (for +X-axis tracking) and then key VERB 37 ENTR 20 ENTR to restart P20.

> NOTE.—When P20 has been temporarily terminated (by request for final targeting solution) or is operating in the background (not in PROG lights), a VERB 37 ENTR 20 ENTR causes P20 to restart after the initialization displays, viz., NOUNS 06, 78, and 79. (See Figure 4.2.1-1, Initial-condition B.)

The first display in the restarted P20 program ($\Delta\theta$ >10 deg) will be a flashing VERB 50 NOUN 18, "Please perform automatic maneuver to tracking attitude." When the maneuver has been completed (as in Sequence I,E, step 3), the crew keys VERB 83 ENTR to start the Rendezvous Parameter Display Routine (R31):

FL VERB 16 NOUN 54

R1	+xxx.xx	n. mi.	Range
R2	±xxxx.x	ft/sec	Range rate
R3	+xxx.xx	deg	theta

The NOUN 54 display is updated every 2 seconds. When the crew is ready to terminate R31, he keys PRO. Typically, he would then key VERB 37 ENTR 47 ENTR to call the Thrust Monitor Program (P47) for monitoring the manually controlled final docking maneuver.

4.2.1.2.3 Program Alarms.—Viewing a PROG alarm light on the DSKY, the crew keys VERB 05 NOUN 09 ENTR for a display of the alarm code—if the code has not already been displayed by the CMC. After taking corrective action, the crew keys RSET to turn off the PROG light and alarm and continues with the program. Possible alarms encountered during rendezvous navigation are as follows:

a. Alarm 00116 indicates the optics were switched to OFF from ZERO before the 15 sec optics zeroing time had elapsed. Set the OPTICS ZERO switch to ZERO, key RSET, wait 15 sec and continue normal operation.
b. Alarm 00120 indicates optics not zeroed at the time of an optics torque request. Set OPTICS ZERO switch to OFF, then to ZERO. Key RSET and wait 15 sec before continuing normal operation.
c. Alarm 00121 indicates a mark was made at the time of a CDU switching transient or vehicle rotation rate too high. Key RSET, and repeat mark.
d. Alarm 00210 indicates IMU not operating. It should be turned on and the stable-member orientation determined before entering P20.
e. Alarm 00220 indicates IMU not aligned. No REFSMMAT is stored. Key RSET and execute P51 (or equivalent; e.g., checklist rapid IMU realign).
f. Alarm 00401 indicates desired angles yield gimbal lock. Key RSET and either select new gimbal angles or maneuver spacecraft to avoid gimbal lock.
g. Alarm 00406 indicates that R23 has been called with P20 Rendezvous Mode not operating. Select P20 before calling the mark routine.

4.2.1.2.4 Restrictions and Limitations.—When the CMC accepts an optics mark, three ICDUs, two OCDUs, and the time of the mark are stored in a buffer, where the data are automatically incorporated into the state vector. Should marks be taken faster than about one every 20 seconds, however, there is a chance that the data will be lost. Also, after the last mark, about 15 sec should be allowed for processing the mark.

An additional restriction is that the W-matrix should never be re-initialized to values greater than 328 ft/sec and 51,647 ft. (The W-matrix is discussed in paragraph 4.2.1.2.5 and in the "Introduction to Coasting Flight Navigation," subsection 4.1.)

TABLE 4.2.1-II

MANUAL RENDEZVOUS PROCEDURE SUMMARY (SHEET 1 OF 5)

Step	Entry	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
				I. INITIALIZATION				
A, B, C, D	---	---	---	---	---	---	Perform preliminary procedures as described in paragraph 4.2.1.2.2.2.	---
E-1	VERB 37 ENTR xx ENTR, where the rendezvous mode of P20 is inactive and xx is 31-36.* (Initial-condition C)	---	P20	Initiate Rendezvous Navigation.	---	• Check REFSMMAT Turn on P20 • Select LM state vector for update. • Set V50N18FL • Set TRACKFLG • Set UPDATFLG • Set RNDVZFLG • Extrapolate CSM and LM state vectors to present time • Load Option 0 into R2 of Noun 06. • Load Noun 78 with γ 000.00 deg (R1); ρ = -035.00 deg (R2); and OMICRON 000.00 deg (R3). • Load Noun 79 with the last R03 designated deadband.	---	Where xx is 72-75, the program proceeds to first display in Pxx without turning on P20. If no REFSMMAT, the program proceeds to first display in Pxx without turning on P20.
E-2	---	FL V50 N25	P3x	Request permission to perform MINKEY Rendezvous.	R1 00017 Checklist Code R2 Blank R3 Blank	• Upon crew's ENTR, proceed with manual (conventional) sequencing. • Upon crew's PRO, proceed with MINKEY sequencing.**	ENTR	**MINKEY sequencing described in paragraph 4.2.1.2.6.
E-3	---	FL V50 N18**	P3x	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	• Upon crew's PRO, perform maneuver to tracking attitude.	PRO	Occurs only if $\Delta\theta$ > 10 deg. Nonflashing V06 N18 occurs only if crew keys PRO on FL V50 N18.
E-4		V06 N18**	P3x	Display final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually. Key VERB 58E to reset STIKFLAG.	A middle-gimbal angle of ±75 deg causes the RCS DAP to terminate the automatic maneuver and to maintain attitude hold. Complete maneuver with the RHC, referencing the FDAI Ball to avoid gimbal lock. Key VERB 58 ENTR.
E-5		FL V50 N18**	P3x	Same as E-3	Same as E-3	• Upon crew's PRO, recycle maneuver. • Upon crew's ENTR, start R52 and proceed to first ordinary targeting display in P3x.	• ENTR For automatic optics positioning set OPTICS ZERO switch to OFF, the OPTICS MODE switch to CMC.	Program proceeds automatically to first regular targeting display in P3x.

TABLE 4.2.1-II

MANUAL RENDEZVOUS PROCEDURE SUMMARY (SHEET 2 OF 5)

Step	Entry	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
				II. RENDEZVOUS TRACKING, NAVIGATION, AND TARGETING				
		The initialization phase of the Rendezvous Navigation Mode ends when the crew is satisfied with the tracking-attitude parameters contained in Nouns 78 and 79, has the tracking attitude established, and is ready to proceed with navigation and targeting. From this point until the crew requests a final targeting solution, he must coordinate his navigation activities with the targeting program in progress. Tracking and W-matrix-reinitialization schedules are discussed in paragraph 4.2.1.2.5. Targeting programs are described in Section ..0.						
A-1	VERB 87 ENTR		P3x	Initiate VHF tracking.		• Upon crew's VERB 87 ENTR begin accumulating VHF range data at 1-minute intervals. • Terminate VHF tracking upon crew's VERB 88 ENTR, VERB 37 ENTR xx ENTR, or upon crew's request for a final targeting solution (PRO on flashing VERB 16 NOUN 45).	• To initiate VHF tracking, key VERB 87 ENTR. • To terminate VHF tracking, key VERB 88 ENTR.	
A-2		FL V06 N49	P3x	Display excessive update.	R1 xxx.xx n.mi. ΔR R2 xxxx.x ft sec Δv R3 oooox Source code (1 optics, 2 VHF)	• Process marks (R22). • Display magnitude of any excessive update. • After two seconds (priority display), accept crew's PRO to incorporate data; accept VERB 32 ENTR to reject data.	• PRO to accept update. • VERB 32 ENTR to reject update.	Occurs only if there is an excessive update (discussed in paragraph 4.2.1.2.5.1).
B-1			P3x	Update state vector by incorporating optics LOS measurements on the LM.		• Accept and process optics LOS measurements. • Display magnitude of any excessive update.	• Set OPTICS MODE switch to MAN. • Use OHC to center LM in SXT. • Depress MARK button. • Depress MARK REJ to reject mark.	Tracking and W-matrix-reinitialization schedules are discussed in paragraph 4.2.1.2.5. Mark must be rejected within 15 sec.
B-2		FL V06 N49	P3x	Display excessive update.	Same as A-2	Same as A-2	Same as A-2	Occurs only if there is an excessive update (discussed in paragraph 4.2.1.2.5.1).

TABLE 4.2.1-II

MANUAL RENDEZVOUS PROCEDURE SUMMARY (SHEET 3 OF 5)

Step	Entry	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
C-1	---	---	P3x	Update state vector by incorporating COAS LOS measurements on the LM.	---	• Accept crew inputs for X-axis tracking. • Compute required gimbal angles. • Turn on UPLINK ACTY if maneuver 10 deg necessary and it is not the first pass through R61.	• Load R1 and R2 of Noun 78 with -000.00 deg (X-axis tracking). • If UPLINK ACTY illuminates, key VERB 58 ENTR to set V50N18FL and reset STIKFLAG.	---
C-2	---	FL V50 N18	P3x	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to tracking attitude.	PRO	Occurs only if $\Delta\theta$ 10 deg. Nonflashing V06 N18 occurs only if crew keys PRO on FL V50 N18.
C-3	---	V06 N18	P3x	Display final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually. Then key VERB 58 ENTR to reset STIKFLAG.	A middle-gimbal angle of ± 75 deg causes the RCSDAP to terminate the automatic maneuver and to maintain attitude hold. Complete maneuver with RHC, referencing the FDAI Ball to avoid gimbal lock. Key VERB 58 ENTR.
C-4	---	FL V50 N18**	P3x	Same as C-2	Same as C-2	• Upon crew's PRO, recycle maneuver. • Upon crew's ENTR, exit R60, continue X-axis tracking.	• ENTR • Key VERB 54 ENTR to call R23.	---
C-5	VERB 54 ENTR (R23)	FL V06 N94	P3x	Display equivalent shaft and trunnion angles for the alternate LOS.	R1 xxx.xx deg SA (Nominal 00000) R2 xx.xxx deg TA (Nominal · 57470)	---	• Verify equivalent shaft and trunnion angles; load new values as determined by in-flight calibration. • PRO	---
C-6	---	FL V53 N45	P3x	Display number of marks accumulated. Display TFI computed by targeting program operating. Display code indicating final targeting solution has not been requested.	R1 xxBxx VHF-Optics Marks R2 ± xxBxx min-sec TFI R3 -00001 preliminary cycle (R2 and R3 valid only if at NOUN 45 display in P3x.)	• Process marks (R22). • Display magnitude of any excessive update.	• Use RHC to center LM in COAS. • To mark, key ENTR. • To reject mark, key VERB 86 ENTR. • When finished marking, wait 15 sec after last mark and then key PRO.	Maximum in R2 is 59 min 59 sec. "-" denotes before t_{IG}; "+" denotes after t_{IG}. Mark must be rejected within about 15 sec.

TABLE 4.2.1-II

MANUAL RENDEZVOUS PROCEDURE SUMMARY (SHEET 4 OF 5)

Step	Entry	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
C-7	---	FL V06 N49	P3x	Display excessive update.	R1 xxx.xx n.mi. ΔR R2 xxxx.x ft sec Δv R3 oooox Source Code (1 - optics, 2 - VHF).	• After two seconds (priority display), accept crew's PRO to incorporate data; accept VERB 32 ENTR to reject data.	• PRO to accept update. • VERB 32 ENTR to reject update.	Occurs only if there is an excessive update (discussed in paragraph 4.2.1.2.5.1).
D-1	VERB 67 ENTR	Other than a marking or priority display.	P3x	Change W-matrix preset RMS values.	---	• Upon crew's VERB 67 ENTR, calculate and display RSS position and velocity errors.	• VERB 67 ENTR	W-matrix-reinitialization schedules and preset values are discussed in paragraph 4.2.1.2.5.
D-2	---	FL V06 N99	P3x	Display RSS position and velocity errors.	R1 xxxxx. ft(pos err) R2 xxxx.x ft sec (vel err) R3 00001 Option Code (Rendezvous)	• Accept crew-loaded values. • Upon crew's PRO, exit V67E.	Load new values if desired (R3 must contain 00001). • PRO	---
E	VERB 93 ENTR	---	P3x	Reinitialize W-matrix to preset RMS values.	---	---	To reinitialize W-matrix to preset values, key VERB 93 ENTR.	W-matrix-reinitialization schedules and preset values are discussed in paragraph 4.2.1.2.5.
				III. PLANE-CHANGE IMU ALIGNMENT				
	VERB 37 ENTR 52 ENTR (P52)	When a plane-change maneuver is to be performed that requires the CSM's X-axis normal to the orbital plane, the maneuver must be preceded by an IMU Realignment (P52). To effect the desired alignment, the platform is pulse torqued to a pseudo landing-site orientation that lies approximately 45 degrees out of the orbital plane. After realigning the IMU, the crew calls the powered-flight program (P40/P41) to perform the out-of-plane maneuver. When the maneuver has been completed, the crew returns the spacecraft to its original (X-axis in-plane) orientation; the crew then calls P52 to realign the IMU for the actual in-plane landing site. (Refer to paragraph 7.2.2 for P52 procedures.)						
				IV. RENDEZVOUS THRUSTING				
A	VERB 37 ENTR 40/41 ENTR (P40/P41)	Ten to twelve minutes before ignition, the crew requests a final targeting solution (PRO on the flashing VERB 16 NOUN 45). When the final solution has been displayed and recorded, the crew calls the appropriate powered-flight program, either to perform the thrusting maneuver (CSM active) or to perform backup procedures (LM active). (Refer to Section 6.0 for a description of powered-flight programs.)						

TABLE 4.2.1-II

MANUAL RENDEZVOUS PROCEDURE SUMMARY (SHEET 5 OF 5)

Step	Entry	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
B	VERB 37 ENTR 76 ENTR (P76)	After a LM-active maneuver, the crew calls the Target-Δv Program (P76) to change the CSM-resident LM state vector. (P76 is described in paragraph 5.2.11.) When thrusting, state-vector update, and IMU Re-alignments (plane-change) have been completed, the crew calls the next targeting program in the sequence and starts again at I(E) Initialization.						
				V. FINAL PHASE				
A	VERB 37 ENTR 79 ENTR (Initial-condition D)	FL V50 N18**	P79	Display required gimbal angles and request permission to perform automatic maneuver to X-axis tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	• Select Option 4. • Load zeros into Noun 78 (R2). • Upon crew's PRO, perform automatic maneuver.	PRO	** Occurs only if $\Delta\theta$ [illegible] 10 deg. Nonflashing V06N18 occurs only if crew keys PRO on FL V50 N18.
B		V06 N18	P79	Display final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to X-axis tracking attitude. NOTE. – If P47 performed before P79, NOUN 78 (R1) will contain value loaded in P47.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually. Then key VERB 58 ENTR to reset STIKFLAG.	A middle-gimbal angle of ±75 deg causes the RCS DAP to terminate the automatic maneuver and to maintain attitude hold. Complete maneuver with the RHC, referencing the FDAI Ball to avoid gimbal lock. Key **VERB 58 ENTR.**
C		FL V16 N54	P79	Display range, range rate and theta.	R1 xxx.xx n.mi. R2 xxxx.x ft/sec R3 xxx.xx deg	Execute Rendezvous Parameter Display Routine (R31). Update display every 2 sec.	• Monitor • PRO when ready to terminate.	
D		FL V37		• Signal termination. • Request crew to select new program.			Key xx ENTR for new program.	

TABLE 4.2.1-III

REGULAR AND EXTENDED VERBS USED WITH RENDEZVOUS: SUMMARY

(SHEET 1 OF 6)

Astronaut	Purpose	DSKY	CMC Operation	Remarks
V16 N20E	Display present gimbal angles.	R1 + xxx.xx deg Roll R2 + xxx.xx deg Pitch R3 + xxx.xx deg Yaw	---	Noun 20 displays the existing ICDU angles.
V16 N22E	Display CMC-desired gimbal angles.	R1 + xxx.xx deg OGA R2 + xxx.xx deg IGA R3 + xxx.xx deg MGA	---	Noun 22 displays the R61-computed desired ICDU angles—not necessarily the center of the DAP deadband.
V16 N92E	Display desired optics angles.	R1 +xxx.xx deg (SA) R2 +xx.xxx deg (TA) R3 Blank	---	---
V44E	Indicate to the Tracking-attitude Routine (R61) that the LM is on the lunar surface.	---	Set SURFFLAG.	---
V45E	Indicate to the Tracking-attitude Routine (R61) that the LM is not on the lunar surface.	---	Reset SURFFLAG.	---
V54E Load equivalent SA and TA for backup tracking PRO	Call Backup Rendezvous Tracking Sighting Mark Routine (R23)	<u>FL V06 N94</u> R1 + xxx.xx deg (SA) R2 + xx.xxx deg (TA) R3 Blank	Request crew to load the equivalent shaft and trunnion angles for the backup pointing axis. (Nominal for COAS is SA = 000.00 deg, and TA = 57.470 deg.)	R23 can be used for backup tracking with a frozen SXT/SCT (optically operational) by loading the existing shaft and trunnion angles in NOUN 94, and manually tracking the LM with the RHC. The COAS must be in-flight calibrated before used for rendezvous navigation.

TABLE 4.2.1-III

REGULAR AND EXTENDED VERBS USED WITH RENDEZVOUS: SUMMARY

(SHEET 2 OF 6)

Astronaut	Purpose	DSKY	CMC Operation	Remarks
V54E (cont.) ENTR to mark V86E to reject mark PRO (15 sec after last mark) to exit R23	---	<u>FL V53 N45</u> R1 +xxBxx VHF, optics R2 ±xxBxx min, sec TFI R3 xxx.xx deg MGA	Request crew to perform alternate LOS sighting mark; display mark counters, time from ignition (TFI), and middle-gimbal angle at t_{IG}.	R1 contains the number of marks processed by the Rendezvous Data Processing Routine (R22); R2 contains time from t_{IG} — maximum reading, 59B59 ("-" before t_{IG}, "+" after t_{IG}); R3 is always '+' for the last pass through P31–P36 with the IMU aligned. (For preliminary passes through P31–P36, R3 contains -00001; during P30 or P37 or during final passes through P31–P36 with the IMU not aligned, R3 contains -00002.)
V56E	Terminate rendezvous navigation without terminating other major programs.	---	Reset RNDVZFLG,* TRACKFLG, UPDATFLG, UTFLAG.	*Resetting this flag terminates the entire rendezvous-navigation process. Also reset by V37E 00E. Set by selection of P20 Options 0 or 4.
V57E	Call display of flag bit governing post-TPI processing of sensor data (single sensor or dual sensor).	<u>FL V04 N12</u> R1 = 00004 R2 = oooox R3 = Blank	When R2 = 0, FULTKFLG indicates that post-TPI navigation will be performed using data from both sensors (VHF and optics). When R2 ≠ 0, FULTKFLG indicates that post-TPI navigation will be performed using data from only one sensor (VHF or optics).	V57E is only used with automatic W-matrix reinitialization during MINKEY rendezvous. Its function is entirely descriptional, i.e., to inform the Data-processing Routine (R22) whether it is receiving post-TPI data from one or both sensors (should be performed before the first mark post-TPI).

TABLE 4.2.1-III

REGULAR AND EXTENDED VERBS USED WITH RENDEZVOUS: SUMMARY

(SHEET 3 OF 6)

Astronaut	Purpose	DSKY	CMC Operation	Remarks
V58E	Allow RCS DAP to resume automatic attitude control and allow R61 to call R60.	---	Reset STIKFLAG and set V50N18FL flag.	STIKFLAG is set whenever the RHC is removed from detent, with the CMC CONT switch in the CMC position. Once set, the flag can only be reset by the selection of a new program or by V58E. The V50 N18FL flag is initially set by any V37E xxE (xx $\neq$ 00) and then reset during each pass through R61. Consequently, after the initial pass, V58E is required if the crew wishes R61 to call R60 to perform an automatic attitude maneuver.
V60E	Load present gimbal angles (Noun 20) into astronaut-specified-gimbal angle registers (Noun 17).	---	---	Noun 17 provides reference for Mode 3 FDAI Needles (V63E).
V61E	Display discrepancy between existing CDU angles and current DAP command.	---	Start Mode-1 error display. Reset NEEDLFLG. Display in-progress attitude error (difference between Noun 20 and current DAP command) on the FDAI error needles.	Proper operation is when error is within DAP deadband limits.

TABLE 4.2.1-III

REGULAR AND EXTENDED VERBS USED WITH RENDEZVOUS: SUMMARY

(SHEET 4 OF 6)

Astronaut	Purpose	DSKY	CMC Operation	Remarks
V62E	Provide FDAI reference for manual attitude maneuver.	---	Start Mode-2 error display. Set NEEDLFLG and N22ORN17 flag. Display total attitude error (difference of contents N22 and contents N20) on the FDAI error needles.	---
V63E	Provide FDAI reference for manual attitude maneuver to astronaut-specified attitude (Noun 17).	---	Start Mode-3 error display. Set NEEDLFLG and reset N22ORN17 flag. Display total attitude error (difference of contents N17 and contents N20) on the FDAI error needles.	---
V67E	Display, and permit crew to change, W-matrix.	<u>FL V06 N99</u> R1 xxxxx. ft (pos err) R2 xxxx. x ft/ (vel err) R3 00001 option code (rendezvous)	Accept crew-loaded values.	To reinitialize W-matrix to preset values, the crew must key V93E. (See Below.) W-matrix is maintained automatically during MINKEY.
V80E	Select the CMC-resident LM state vector for rendezvous-navigation update.	---	Clear VEHUPFLG to designate the LM state vector for update.	Automatically cleared by initial entry to P20. Therefore, if the crew wishes to designate the CSM state vector for update he should key V81E.

TABLE 4.2.1-III

REGULAR AND EXTENDED VERBS USED WITH RENDEZVOUS: SUMMARY

(SHEET 5 OF 6)

Astronaut	Purpose	DSKY	CMC Operation	Remarks
V81E	Select the CMC-resident CSM state vector for rendezvous-navigation update.	---	Set VEHUPFLG to designate the CSM state vector for update.	Once set, VEHUPFLG is cleared by V80E or by "permanently" terminating and reentering P20.
V82E	Call Orbit Parameter Display Routine (R30).	See paragraph 9.2.3.		Display apolune, perilune, and time of free fall to 35,000 ft. (Also used in earth orbit.)
V83E	Call Rendezvous Parameter Display Routine No. 1 (R31).	<u>FL V16 N54</u> R1 xxx.xx n.mi. range R2 xxxx.x ft/sec range rate R3 xxx.xx deg theta	Calculate and display (two-second updates) range and range rate between CSM and LM. Calculate and display angle (theta) between CSM +X-axis and the local-horizontal plane.	Negative sign in R2 denotes closing. When finished with display, key PRO. Called automatically by P79.
V85E	Call Rendezvous Parameter Display Routine No. 2 (R34).	<u>FL V16 N53</u> R1 xxx.xx n.mi. range R2 xxxx.x ft/sec range rate R3 xxx.xx deg phi	Calculate and display (two-second update) range and range rate between CSM and LM. Calculate and display angle (phi) between optics SLOS and the local-horizontal plane.	Negative sign in R2 denotes closing. When finished with display, key PRO.
V86E	Reject last R23 mark taken.	---	Erase last sighting mark taken during the Backup Rendezvous Tracking Sighting Mark Routine.	Must be performed within approximately 15 seconds of mark.

TABLE 4.2.1-III

REGULAR AND EXTENDED VERBS USED WITH RENDEZVOUS: SUMMARY

(SHEET 6 OF 6)

Astronaut	Purpose	DSKY	CMC Operation	Remarks
V87E	Allow R22 to accept VHF range data.	---	Set VHFRFLAG.	VHFRFLAG is set automatically in MINKEY, but must be set manually for a manually sequenced rendezvous incorporating VHF range data in the state-vector update. VHF ranging will then continue automatically (within 327.67 n.mi.) until the crew keys V88E.
V88E	Stop R22 from accepting range data.	---	Reset VHFRFLAG.	See V87E.
V89E	Call Rendezvous Final Attitude Routine (R63).	See paragraph 2.2.1.		R63 can only be called from P00.
V90E	Call Rendezvous Out-of-Plane Display (R36).	See paragraph 9.2.4.		Displays CSM out-of-plane distance (Y) and rate ($\dot{Y}$) and LM out-of-plane rate ($\dot{Y}$).
V93E	Reinitialize W-matrix.	---	Reset RENDWFLG.	V93E reinitializes W-matrix to preset values. (See V67E) W-matrix is automatically maintained during MINKEY.

A limiting factor regarding VHF range data is that the input counter to the CMC is modulo 327.68. At 327.67 n.mi., the counter begins again at zero, such that at a range of 350 n.mi., for example, the counter will contain the value, 22.32. Consequently, the CMC does not process VHF range data when the onboard range estimate is greater than 327.67 n. mi. If the onboard estimate is less than, or equal to, 327.67 n. mi., however, when the actual range is somewhat larger than the modulo value, an excessive-update display (flashing VERB 06 NOUN 49) is likely. The crew should reject the update and either terminate VHF tracking (VERB 88 ENTR) or continue to reject updates until reasonableness criteria are satisfied. (See paragraph 4.2.1.2.5.1.)

Also, depending upon scaling, there is a minimum range at which P20 is effective. Although it is difficult to establish definite limits, since scaling may differ for different missions (e.g., earth versus lunar), operation with current scaling is not recommended for ranges less than about 3 n. mi.

4.2.1.2.5 Tracking and W-Matrix-reinitialization Schedules.—The Rendezvous Mode of P20 uses measurements of the relative state of the two vehicles to solve for the inertial state of one vehicle. The extent to which the state vector updated by P20 conforms to actual position and velocity in inertial space will depend, therefore, upon how well the inertial position and velocity of the vehicle whose state vector is not updated are known. If there were no uncertainties in the direct measuring of range and LOS between the two vehicles, determining the relative state vector would be simply a matter of taking measurements, comparing the results with values predicted on the basis of the current best estimate of the two state vectors, and updating one of the estimated states such that the predicted and measured values agree. Measuring uncertainties do exist, however, calling for a statistical weighting matrix (W-matrix) and an a priori sensor variance for determining how much emphasis is to be given to the measured data, in updating the state, and how much is to be given to the current state estimate. The initial W-matrix values are based on statistical studies to determine what the expected mean-square errors in position and velocity will be before any measurements are taken; as measurements are taken, however, and the confidence in the relative state vector increases, the W-matrix is itself updated such that statistical weighting becomes more and more in favor of the current estimate and less in favor of new measurements. Due to incomplete filter modeling and computational limitations of the computer, the weighting in favor of the measurements becomes, in time, too small. To prevent this, the W-matrix must be periodically reinitialized (WRI) to its padloaded or reloaded values.

Ordinarily, Mission Planning provides a schedule specifying when, what kind, and how many measurements should be taken, as well as when the W-matrix should be reinitialized—and to what values. (Figure 4.2.1-4 is a typical tracking schedule provided by Mission Planning.) Such a schedule results from analyses of digital simulations of the actual computer operations for a particular mission. For inflight contingencies, however, requiring the crew to improvise a tracking and reinitialization strategy, an acceptable rule of thumb is to (a) reinitialize every 40 minutes, but allowing 10–15 minutes of tracking before a final targeting solution, (b) take several marks immediately before, immediately after, and halfway between each reinitialization, and (c) reinitialize before taking marks after a maneuver if more than 60 minutes have elapsed since the last initialization.

The philosophy underlying the rule of thumb is to reinitialize more often than may be necessary but less often than would significantly degrade performance. In applying the rule, however, the crew should be aware of three other factors:

1. W-Matrix initial values are selected on the basis of anticipated state-vector error—the larger the expected error, the larger the initialization values. Typical reinitializing values during rendezvous are 2000 ft, 2 ft/sec, and (in the LGC) 5 m rad—corresponding to the RMS values of probable position, velocity, and radar-bias errors respectively. Immediately following lunar orbit insertion, however, when the large powered-flight maneuver may have produced large state-vector uncertainties, typical WRI values are 10,000 ft, 10 ft/sec, and 15 m rad (LGC).
2. The larger the WRI values, for a given a priori sensor variance, the more sensor data required to smooth the WRI transient. Even for the large initial values following lunar orbit insertion, however, an accurate state vector estimate is available for the final targeting computation if SXT marks are taken in batches of three or four marks each—typically, one batch immediately after WRI, a second batch halfway before a third batch immediately preceding the next WRI or the final targeting computation.
3. The two-sensor procedure following transfer-phase initiation (TPI)—when the tracking geometry is such as to rapidly decrease the size of the matrix with each mark—is to reinitialize before taking any marks following a maneuver. The single-sensor post-TPI procedure is (a) to take marks with no WRI between TPI and the first midcourse correction (MCC1) and (b) after MCC1, to take on batch (three marks) and then reinitialize. Tracking then continues in the normal pattern.

Paragraphs 4.2.1.2.5.1–4.2.1.2.5.4 present some general recommendations for mark-reject and accept procedures, as well as recommended procedures when state-vector updates indicate a divergent navigation solution. Two graphs (Figures 4.2.1-5, -6) present actual state-vector updates (that exceed R_{MAX}, v_{MAX} values) for a CMC and LGC bit-by-bit simulation of the nominal Mission F rendezvous. (Note: R_{MAX} v_{MAX} limits were not exceeded after post-CSI V93.) Also shown are one-sigma state-vector updates.

The procedures here attempt to cover some off-nominal conditions. All off-nominal conditions, however, cannot be simply generalized; each case must be considered in the light of all information available; e.g., previous marking history may indicate a three-sigma radar, extremely large initial state errors that require a long tracking period to resolve, or degraded PIPA performance as evidenced by large state-vector updates after a burn.

4.2.1.2.5.1 State Vector Update.—The following are mission phases in which the largest state-vector updates can be expected:

a. Initial period of tracking after insertion
b. After maneuvers—either a burn for active vehicle or P76 for passive vehicle
c. Beginning of tracking after long period with no tracking
d. After W-matrix re-initialization.

Reasonable values for updates are a function of the phase in which they occur. Typically, a δR of 12000 ft and a δv of 12 ft/sec before CSI, 5000 ft and 5 ft/sec after CSI, can be expected during phases of expected large updates. Should the update value exceed reasonableness values, the crew should reject the first mark, ensure that the sextant is actually tracking the LM, check VHF range against nominal, and repeat the mark. If the second mark yields a similar, or slightly larger, update, accept the mark and look for a decrease in the size of the update as marks continue. If update values do not become smaller, apply divergence procedure (paragraph 4.2.1.2.5.2 below).

Anomalous updates during "steady-state" conditions, i.e., not during phases of expected large updates, are those that are larger than the preset R_{MAX}, v_{MAX}. For this condition, the crew follows the same procedure described for larger-than-reasonable updates during expected-large-update phases. One bad mark could be the result of poor sighting technique or large random error. If anomalous updates continue, use divergence procedure (paragraph 4.2.1.2.5.2).

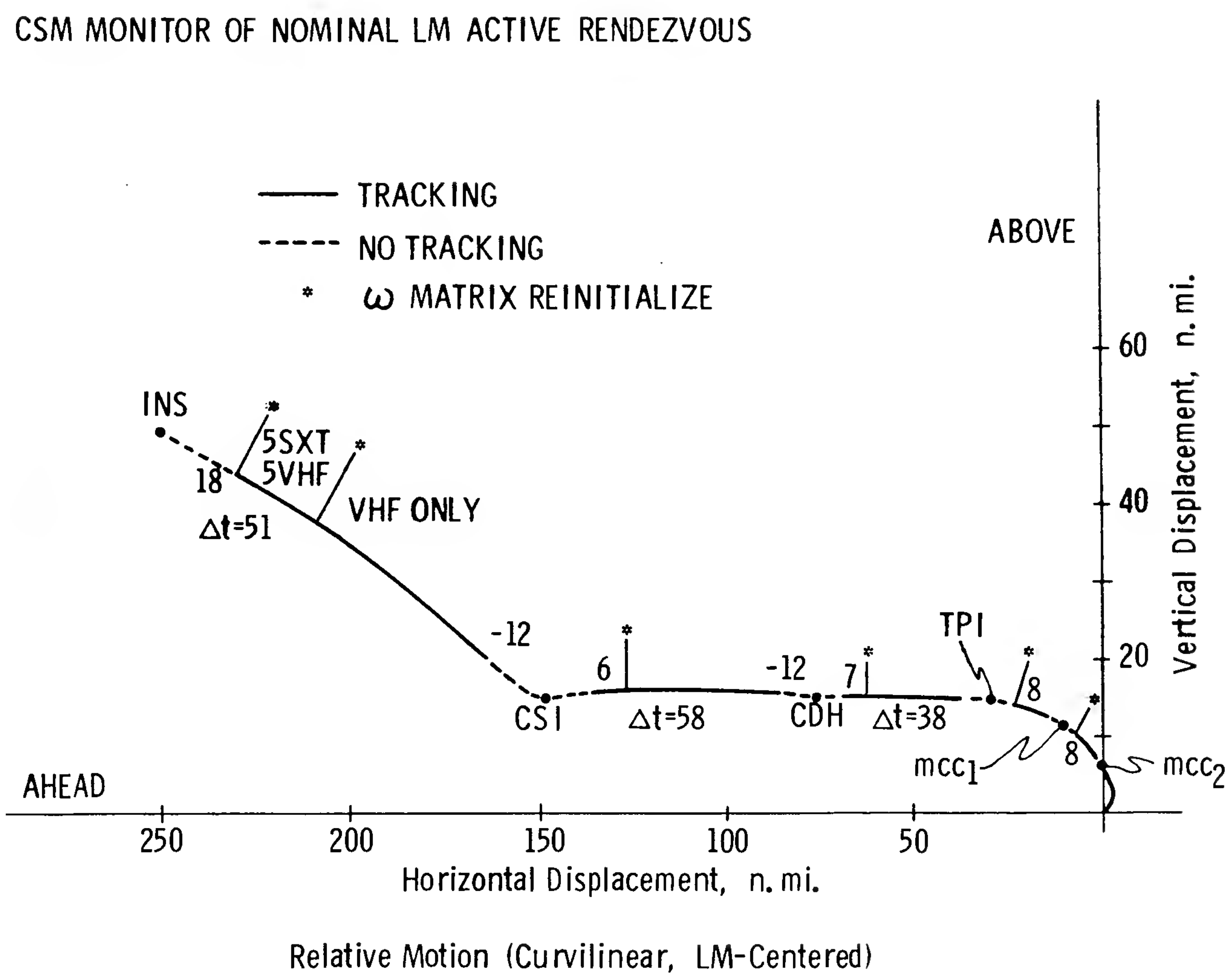


Figure 4.2.1-4. Typical Tracking Schedule for a CSM-monitored — LM-active Rendezvous

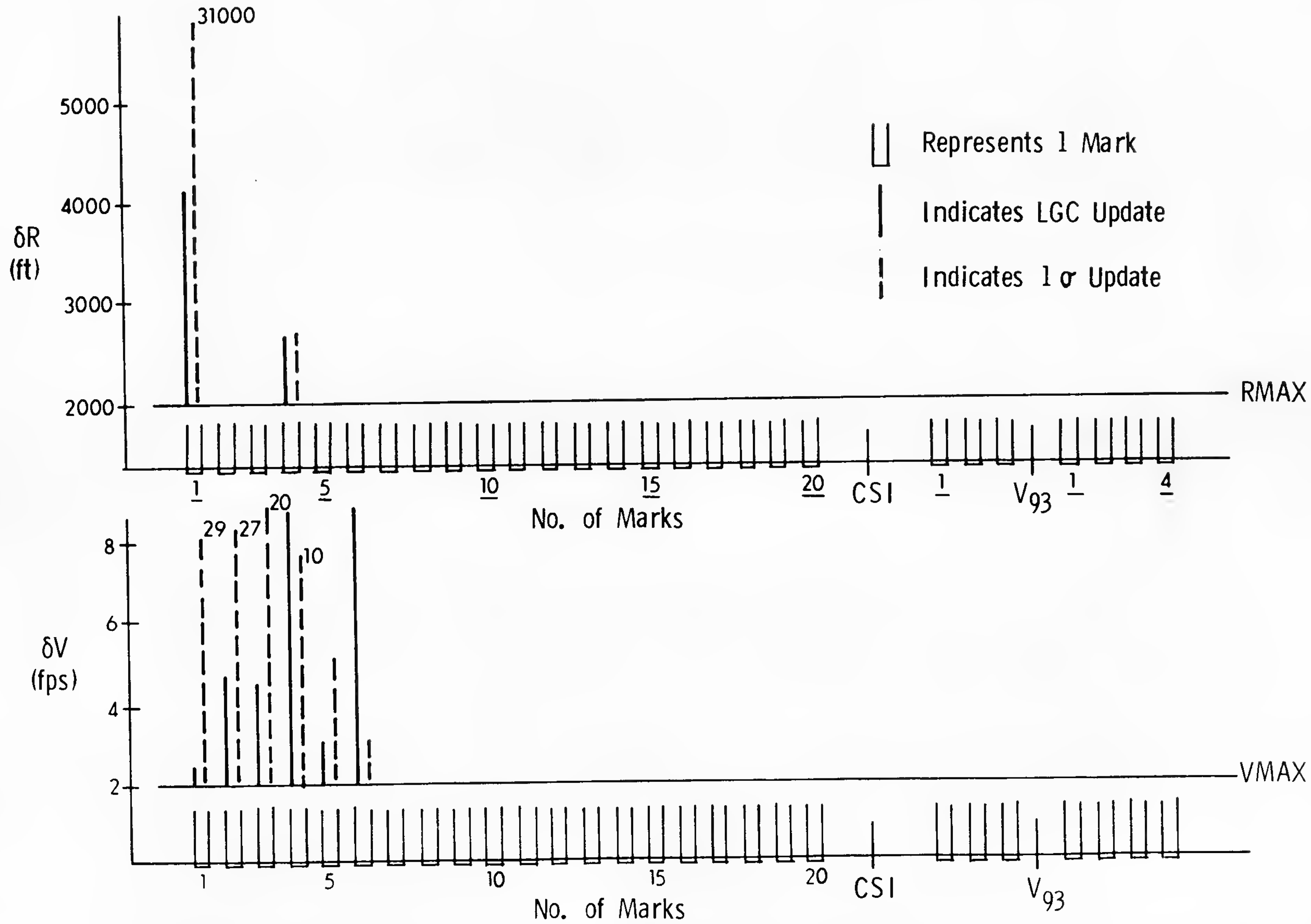


Figure 4.2.1-5. Typical RR δR, δv Updates

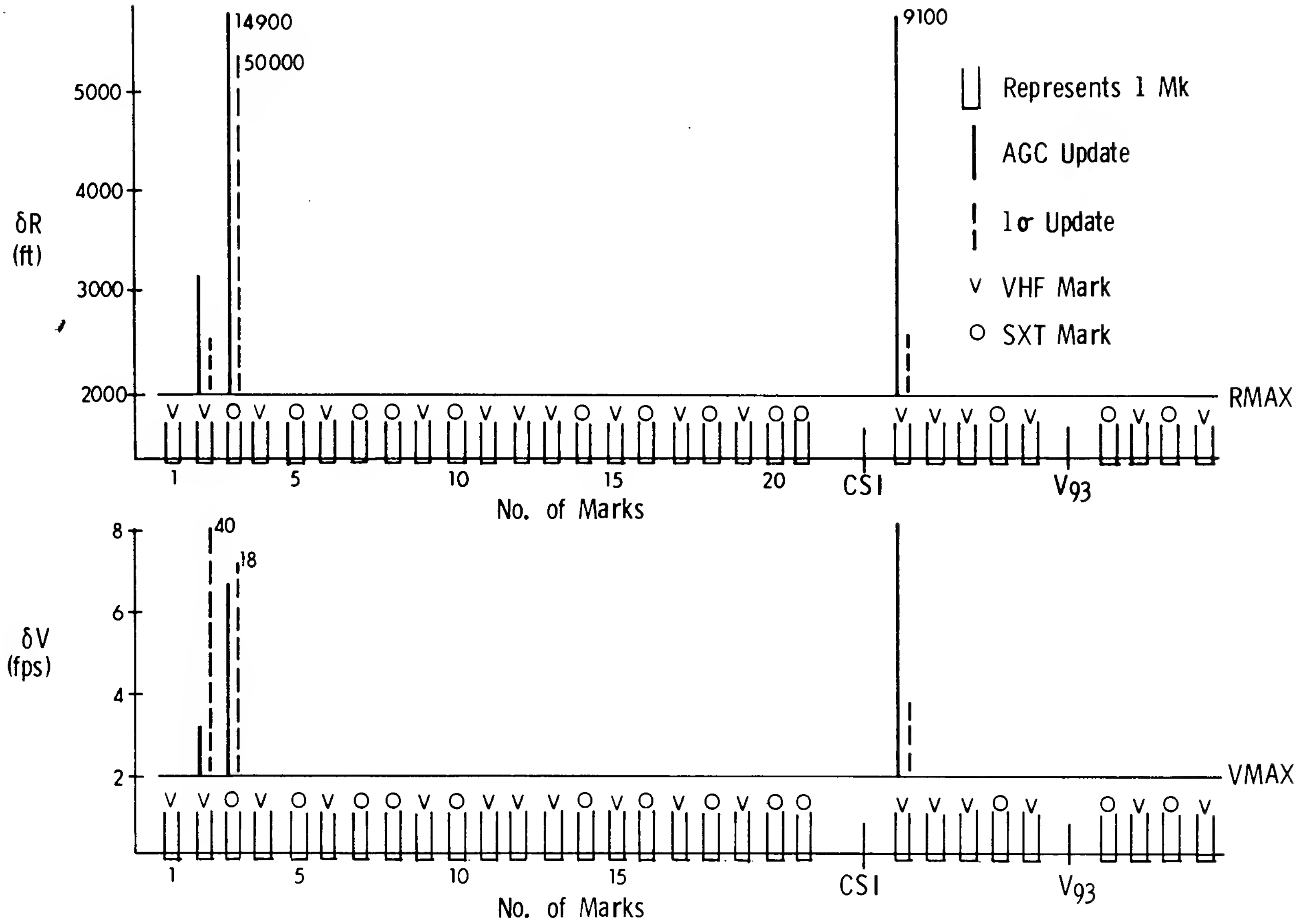


Figure 4.2.1-6. Typical VHF and SXT δR, δv Updates

4.2.1.2.5.2 Divergence Procedures.—There are six categories of anomalous conditions requiring special procedures:

1. Condition. State-vector updates are not decreasing (and are near the 12000 ft, 12 fps limits) after 10 accepted marks after insertion. Procedure. Re-initialize W-matrix; zero out bias estimates (not W-matrix bias loads). (Bias estimates apply only to the LGC.)

   Implication. Initial relative errors were too large for initial W-matrix to handle; repeat entire procedure and if same results occur, assume system failure unless other vehicle is experiencing same difficulty. (This indicates ground uplink yielded relative errors of such a magnitude that system cannot resolve them.)

2. Condition. State-vector updates exceed R_{MAX}, v_{MAX} for three unaccepted marks during steady-state operation (where it is assumed a period of acceptable tracking precedes these marks). Procedure. Re-initialize W-matrix and accept first mark. If updates do not decrease after four or five accepted marks, system has failed.

3. Condition. State-vector updates exceed 5000 ft, 5 ft/sec for three unaccepted marks during steady-state operation (no excessive updates preceding as above). Procedure. Re-initialize W-matrix and accept first mark. If updates continue to exceed 5000 ft or 5 ft/sec, or do not decrease after four or five accepted marks, system has failed. If updates converge, realize that you may be operating with a sensor that has bias and that a state-vector error will exist. (The value of this error should be approximately the size of the first update after W-matrix re-initialization.)

4. Condition. Last mark before a maneuver exceeds R_{MAX}, v_{MAX}. Procedure. If you were in steady-state conditions before this, reject last mark. If updates were exceeding R_{MAX}, v_{MAX} before last mark, but were decreasing, accept mark.

5. Condition. Unreasonably large Position Update. Procedure. Reject; anything larger than range/5 can cause system to be unstable.

6. Condition. Unreasonably large update is accepted and is known to have been incorrect (system malfunction discovered; bad P76, bad ground uplink, etc.) Procedure. (a) Fix malfunction; (b) get new ground uplink, if possible, and start again; (c) if uplink not possible, reinitialize W-matrix to approximate position value of update, velocity value 0.001 x position value, zero out bias estimates (not in W-matrix load) and proceed. (Bias estimates apply only to the LGC.)

4.2.1.2.5.3 Summary of Correction Procedures for Anomalous Updates During Steady State Tracking.—

1. Always check out sextant first—after a VHF mark and V88.
2. If both sensors fail procedure—V93 and start over.
3. If only one sensor fails procedure—proceed with other sensor only. (See Sensor Verification Table.)

Sensor Verification
(assumes first mark rejected)

ΔR, Δv(N49) <1 n. mi., 5 fps	ΔR, Δv(N49) >1 n. mi., 5 fps
accept second and third marks (PRO) if fourth mark under limit -- sensor data OK if fourth mark over limit-- sensor data bad	• reject three consecutive marks that exceed above limits (including first mark) (sensor data bad)

4.2.1.2.5.4 Recovery Procedure After Extremely Large Update Known To Be Incorrect.—

. Record NOUN 49 value of ΔR (xxx.xx n. mi.)

. Terminate updates (VERB 88 ENTR)

. VERB 67 ENTR, load NOUN 99 with

R1 = ΔR times 6000 (xxxxx. ft)
R2 = ΔR times 6 (xxxx.x fps)
R3 = +00001

. PRO

. VERB 93 ENTR

. Resume updates (VERB 87 ENTR)

4.2.1.2.6 MINKEY Rendezvous.—Minimum-key-stroke (MINKEY) rendezvous differs from conventionally sequenced rendezvous as follows:

a. Instead of selecting each program as it is required in the rendezvous sequence, the crew simply keys in the appropriate targeting program for a given point in the sequence; this causes an immediate display of FL VERB 50 NOUN 25 (R1 = 00017), "Please perform MINKEY Rendezvous." A PRO response initiates automatic sequencing of the rendezvous programs. (An ENTR response inhibits MINKEY and allows manual sequencing. See paragraph 4.2.1.2.2.)
b. Instead of the crew's manually establishing a wings-level attitude, an erasable quantity will be preloaded, designating the desired attitude for performing the rendezvous. The CMC will then compute and execute the appropriate attitude maneuvers.
c. In the MINKEY sequence, the CMC reinitializes the W-matrix according to predetermined criteria requiring no consideration by the crew.
d. When the onboard range estimate is less than 327.67 n. mi., VHF range data are collected and processed continuously, without crew initiation.
e. Alignment procedures for plane-change maneuvers simplified.
f. Instead of crew's calling P76 and manually loading LM-active thrusting parameters to update the CMC'S LM state vector, MINKEY calls P76 after each burn and displays the appropriate update parameters.

4.2.1.2.6.1 MINKEY Sequence Initiation.—The crew can begin the MINKEY sequence at any one of the six reset points: (1) Pre-Height-adjust Maneuver (HAM), (2) Pre-Coelliptic Sequence Initiation (CSI), (3) Pre-Plane Change (PC), (4) Pre-Constant-delta Altitude (CDH), (5) Pre-Transfer-phase Initiation (TPI), or (6) Pre-Transfer-phase Midcourse 1 (MCC1). At which reset point the sequence begins is determined by the targeting program selected. If the crew wishes to enter the sequence before the height adjustment maneuver, he selects major mode P31; if he wishes to enter the sequence before CSI, he selects major mode P32; etc. The MINKEY sequence, including reset points, is as follows:

P31 (VERB 37 ENTR 31 ENTR)

1. Start Rendezvous Navigation (P20); execute maneuver to tracking attitude; begin VHF tracking; and perform Height-adjustment Targeting (P31).
2. Perform Powered-flight Program (P40/P41).*
3. Perform Target-Δv Program (P76). Continue to step 4.

P32 (VERB 37 ENTR 32 ENTR)

4. Start Rendezvous Navigation (P20); execute maneuver to tracking attitude; begin VHF tracking; and perform CSI Targeting (P32).
5. Perform Powered-flight Program (P40/P41).
6. Perform Target-Δv Program (P76). If number of apsides (NN of R1 in NOUN 55) before CDH is less than 4, continue to step 7; if number of apsides before CDH equals 4, return to step 1; if number of apsides before CDH is greater than 4, return to step 4.

> NOTE.—When the number of apsides before CDH is greater than 4, the NN value in R1 of NOUN 55 will be (incorrectly) 00001. The crew must overwrite with correct value.

P36 (VERB 37 ENTR 36 ENTR)

7. Start Rendezvous Navigation (P20); execute maneuver to tracking attitude; begin VHF tracking; and perform Plane-change Targeting (P36).

8a. Sequence I (PC $v_G \neq 0$ ft/sec).—Perform modified-P52 IMU alignment —PRO on FL VERB 50 NOUN 25 (R1 = 00020); then perform powered-flight program (P40/P41) and the Target-Δv Program (P76). Call P20 to return spacecraft to tracking attitude; then re-establish IMU alignment (modified P52). Continue to step 9.

8b. Sequence II (PC $v_G \neq 0$ ft/sec).—Omit IMU alignment—ENTR on FL VERB 50 NOUN 25 (R1 = 00020); perform the RCS powered-flight program (P41) and the Target Δv Program (P76). Continue to step 9.

8c. Sequence III (PC $v_G = 0$ ft/sec).—Omit PC maneuver and perform the Target Δv Program (P76). Continue to step 9.

P33 (VERB 37 ENTR 33 ENTR)

9. Start Rendezvous Navigation (P20); execute maneuver to tracking attitude; begin VHF tracking; and perform CDH Targeting (P33).

---

*Whenever MINKEY calls a powered-flight program, the criterion for P40/P41 is whether the required $v_G \geq 7$ ft/sec (call P40) or < 7 ft/sec (call P41). The one exception is when PC pulse torquing is bypassed in P36. In that instance, the program calls P41 regardless of v_G.

10. Perform Powered-flight Program (P40/P41).
11. Perform Target-Δv Program (P76). Continue to step 12.

P34 (VERB 37 ENTR 34 ENTR)

12. Start Rendezvous Navigation (P20); execute maneuver to tracking attitude; begin VHF tracking; and perform TPI Targeting (P34).
13. Perform Powered-flight Program (P40/P41).
14. Perform Target-Δv Program (P76). Continue to step 15.

P35 (VERB 37 ENTR 35 ENTR)

15. Start Rendezvous Navigation (P20); execute maneuver to tracking attitude; begin VHF tracking; and perform TPM (MCC1) Targeting (P35).
16. Perform Powered-flight Program (P40/P41).
17. Perform Target-Δv Program (P76). Continue to step 18.
18. Start Rendezvous Navigation (P20); execute maneuver to tracking attitude; start VHF tracking; and perform TPM (MCC2) Targeting (P35).
19. Perform Powered-flight Program (P40/P41).
20. Perform Target-Δv Program (P76). Continue to step 21.
21. Start P20, perform maneuver to X-axis tracking attitude, and display range, range rate, and theta every 2 sec (P79).
22. Upon crew's PRO, flash VERB 37 to request selection of new program (P00 or P47). END OF MINKEY SEQUENCE

4.2.1.2.6.2 Heads-up/Heads-down Option.—A heads-up rendezvous is defined as a rendezvous with the spacecraft oriented such that its Y-axis lies approximately along the negative of the angular momentum vector; a heads-down rendezvous is defined as a rendezvous with the spacecraft oriented such that its Y-axis lies approximately along the positive of the angular momentum vector. Whether the rendezvous orientation is heads-up or heads-down is determined by the value loaded in NOUN 78, Register R3. (+000.00 deg designates heads-up; +180.00 deg designates heads-down.) When the rendezvous sequence is first initiated, NOUN 78 (R3) is automatically loaded to +000.00 deg if HDSUPFLG is set; automatically loaded to +180.00 deg if HDSUPFLG is reset.

NOTE.—HDSUPFLG configuration can be changed by the Channel and Erasable Modification Routine (R01). The flag is only looked at, however, when MINKEY is first selected —by PRO to FL VERB 50 NOUN 25 (R1 = 00017) or by VERB 37 ENTR 79 ENTR—and Option 4 of P20 has not been previously selected (RNDVZFLG and AZIMFLAG set). Once the MINKEY sequence has begun, therefore, changing the configuration of HDSUPFLG will have no consequence (unless P20 is "permanently" terminated—see Figure 4.2.1-1—and MINKEY re-selected.)

The contents of NOUN 78 (R3) can be manually changed, however, without interrupting the MINKEY sequence, by keying VERB 23 NOUN 78 ENTR and loading the desired OMICRON. The CMC will then compute and execute a maneuver to the newly designated orientation.—NOUN 78 is interrogated on every pass through the Tracking-attitude Routine (R61), or once about every 8 seconds—unless delayed by R22 mark processing.

Temporary interruption of the MINKEY sequence—by manual selection of P40 for example—can be effected without concern that the last-designated heads-up/heads-down option will be affected when the MINKEY sequence is reinitiated at one of the reset points, e.g., VERB 37 ENTR 35 ENTR.

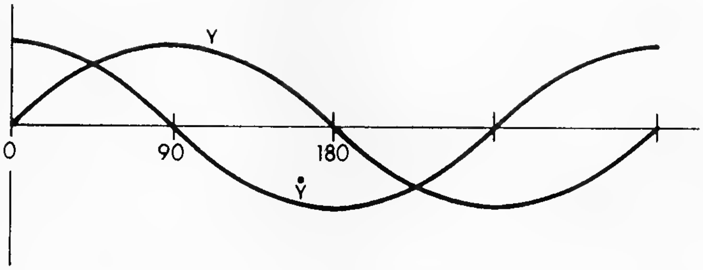
When the rendezvous sequence is first initiated (at any reset point), NOUN 78 Registers R1 and R2 are automatically loaded with the preset values +000.00 and -035.00 deg respectively (preferred tracking attitude). If the crew wishes, he can subsequently change the preset values by keying VERB 2x NOUN 78 ENTR. As with R3, the last-loaded values will be unaffected by subsequent reset-point entries to the rendezvous sequence, so long as RNDVZFLG remains set. When the Rendezvous-final Program (P79) is initiated, however, whether manually or in the MINKEY sequence, Register R2 is changed automatically to +000.00 deg (X-axis tracking attitude). Subsequent entry at a MINKEY reset point would then result in X-axis tracking.

NOTE 1.—P79 does not reinitialize R1 of NOUN 78 to the nominal zero value. Consequently, if a non-zero value has been manually loaded into this register, it must be manually corrected for P79 operation.

NOTE 2.—If P79 is selected when REFSMMAT flag is zero (REFSMFLG reset), the PROG number will appear, but the program will not function.

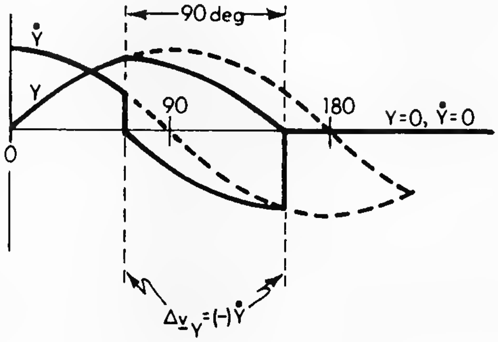
NOTE 3.—If P47 is called during P20, the values in NOUN 78 (R1, R2) will be altered and must be reloaded manually before use with P20 tracking.

4.2.1.2.6.3 Plane Changes.—The underlying theory of plane-change targeting is explained in more detail in the introduction to the targeting programs (Users' Guide subsection 5.1). The essential points are that the paths of two bodies in noncoplanar orbits about the same center of mass will cross every 180 deg, that the maximum displacement between the orbits occurs 90 deg out of phase with the crossings, and that the rate of displacement change is greatest at the crossings and is zero at the points of maximum displacement. Thus, the rate (Y-dot) that the lateral distance (Y) between the two bodies changes is greatest at the crossings, or nodes (Y = 0), and is least (Y-dot = 0) at the points of maximum displacement (antinodes).



This allows the following scheme for establishing coplanar orbits during rendezvous:

1. At any given time, the active vehicle performs a thrusting maneuver resulting in Y-dot = 0, thus establishing an antinode and, 90-deg later, a node (Y = 0, Y-dot = maximum).



2. A second thrusting maneuver is performed at the node in order to null Y-dot and, thereby, establish the coplanar condition (Y = 0, Y-dot = 0).

Accordingly, the MINKEY sequence incorporates a Y-component of $\Delta \underline{v}$ equal to (-) Y-dot. This sets up the desired node condition 90 deg of central transfer angle later (CSM trajectory), when the MINKEY sequence schedules a plane-change maneuver.

As applied to CSI, P32 automatically displays (NOUN 90) the out-of-plane data for astronaut approval each time the crew asks for a targeting solution, whether preliminary (VERB 32 ENTR on the NOUN 45 display) or final (PRO on the NOUN 45 display). The CMC will automatically incorporate the (-) Y-dot CSM as the $\Delta \underline{v}$ Y-component in NOUN 81. Then, after the CSI maneuver, the CMC calls P36 to target the second Y-dot-nulling maneuver at the appropriate time.

4.2.1.2.6.4 W-Matrix Reinitializing.—A salient feature of MINKEY rendezvous sequencing is the elimination of the crew's task of periodically reinitializing the error-transition (W-) matrix. Crew responsibilities regarding the W-matrix during manually sequenced rendezvous are discussed in Users' Guide subsection 4.1 and paragraph 4.2.1.2.5. As a result of mission experience, the behavior of the W-matrix during rendezvous can be predicted with sufficient confidence to incorporate a MINKEY reinitialization scheme that totally relieves the crew of W-matrix consideration.

The reinitialization (WRI) scheme shown in Figure 4.2.1-7 is essentially a mechanization of the ground rules provided to the crews for improvising a manually sequenced, contingency WRI schedule. The basic considerations are (1) to avoid premature reinitializations, which would degrade the W-matrix's error-correction and correlation performance; (2) to avoid late reinitializations, which would allow the W-matrix to become superannuated. Specifically, a superannuated W-matrix is one that has either (a) shrunk to the point that incoming measurements are downweighted excessively (loss of filter gain) or (b) disintegrated in accuracy to the point that it is no longer reliable. Loss of filter gain is a function of the measurement geometry and the number of marks taken since the last WRI and is the result of incomplete error modeling; loss of reliability is a function of time since the last WRI and is the result of incorrect error modeling due to computer storage limitations. Since geometry is a factor in the loss of gain, determining when the loss will occur requires a bit-by-bit analysis of simulated computer operations for a particular mission; determining how long the W-matrix can be extrapolated before it becomes unreliable is more difficult, since a major factor is the accuracy of the vehicle state vector not being updated. A generalized scheme that can be mechanized for all contingencies is possible, however, by following a minmax concept of reinitializing more often than may be necessary but less often than would significantly degrade performance.

Accordingly (Figure 4.2.1-7), the principal criterion for allowing a WRI after other than a first mark following a maneuver is whether a specified minimum time (WRDTIME) has elapsed since the last WRI. Typically, WRDTIME is about 40 minutes —long enough for effective correlation and smoothing, short enough to occur well before superannuation. The second criterion is whether no more than a specified maximum time (MINBLKTM, typically 5 minutes) has elapsed since the last mark.

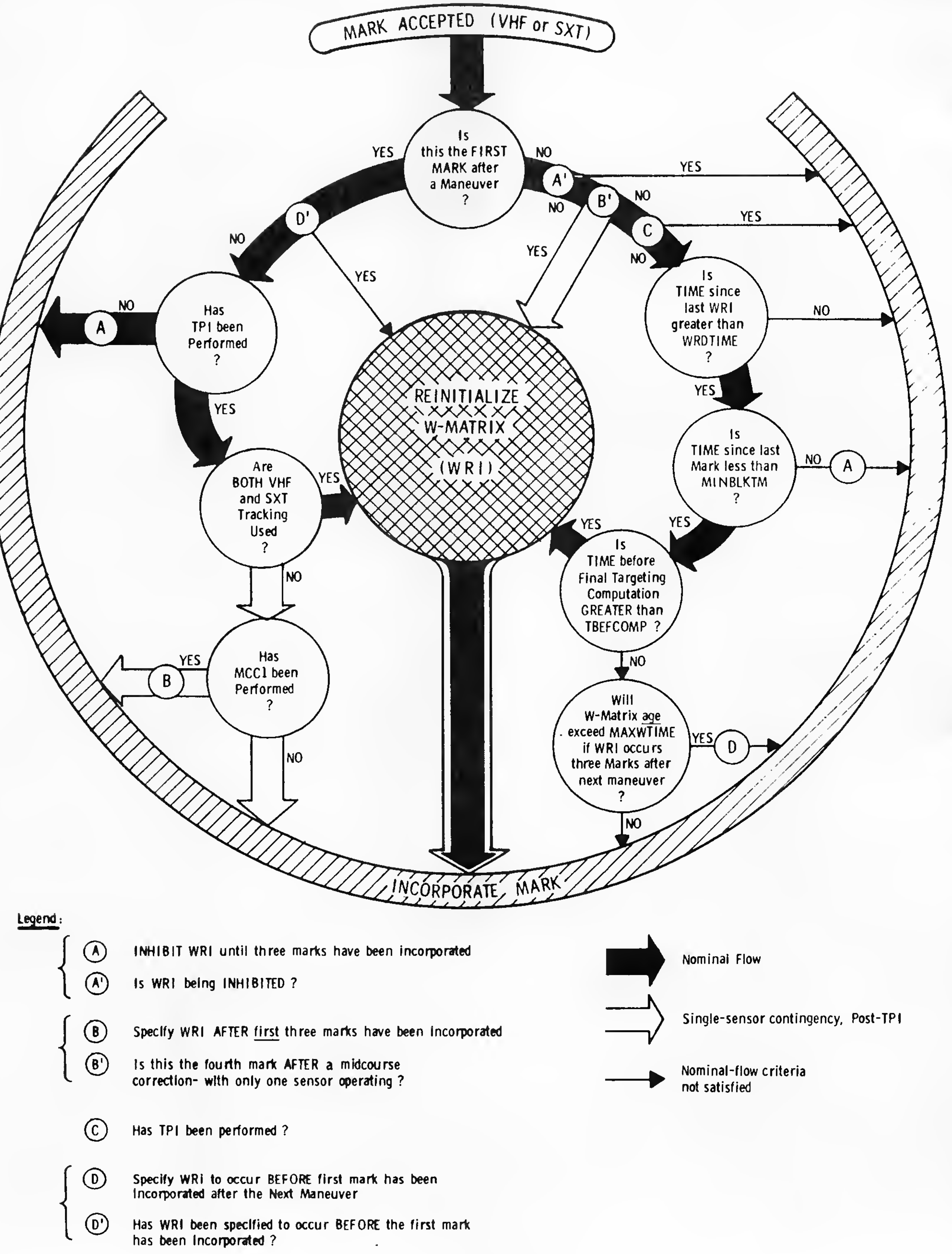


Figure 4.2.1-7. Strategy for MINKEY-Rendezvous W-matrix Reinitialization (WRI)
(This figure is intended to illustrate the general strategy for automatic W-matrix reinitialization. It is not intended to rigorously define program coding. For specific details of coding, therefore, refer to Figure 2.5.3 in GSOP Section 5.)

If more than MINBLKTM has elapsed since the last mark (VHF or SXT),* WRI will be INHIBITed (A) for three marks in order to allow W-matrix correlation to reduce error buildup during the no-mark period. The third criterion for allowing WRI is whether more than a specified minimum time (TBEFCOMP) remains before the final targeting computation. For example, TBEFCOMP will have a preset value of about 10–15 minutes, allowing a sufficient period of post-WRI tracking to provide a correlated W-matrix and a best state-vector estimate for the targeting computation. If the other criteria have been satisfied and more than TBEFCOMP remains before final targeting, WRI is allowed and the mark is incorporated.

Before transfer-phase initiation (TPI), the nominal flow for a first mark following a maneuver is to INHIBIT (A) WRI until three marks have been accumulated. The exception to this is when, as a result of the TBEFCOMP restriction preceding a maneuver, the W-matrix age would exceed MAXWTIME (~1 hour) should WRI be INHIBITed. For this contingency, WRI is specified (D) to occur before (D') the first mark is incorporated.

The other condition when WRI occurs before the first mark is incorporated is in the nominal-flow situation following TPI. The post-TPI geometry is such that filter gain deteriorates more rapidly than in the pre-TPI phase. Consequently, with both VHF and SXT operating, the nominal post-TPI procedure gives higher priority to restoring filter gain than to correlation: WRI occurs on the first mark, and is prohibited (C) on subsequent marks.

Correlation in the unmeasured dimension becomes obligatory, however, when data are being incorporated from only one sensor (as signaled by the crew's VERB 57 ENTR, to load R2 of N12 with 00001—FULTKFLG set). The post-TPI, single-sensor strategy, therefore, is to reinitialize the W-matrix only once between TPI and the second midcourse correction (MCC2). The strategy is mechanized as follows. The first mark following TPI is incorporated without WRI; since subsequent marks between TPI and the first midcourse correction (MCC1) will not pass the TBEFCOMP criterion, no WRI can occur during the TPI-MCC1 phase. Following MCC1 (or any midcourse correction), however, a WRI is specified (B) to occur after the first three marks have been incorporated (B')—regardless of TBEFCOMP. The single WRI, occurring three marks after an MCC, ensures the best post-TPI trade-off between the requirements of one-sensor correlation and filter gain.

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*Throughout the MINKEY section of the Users' Guide, reference to "SXT" reflects nominal conditions. Unless specified otherwise, however, the COAS optics can be used as back-up.

4.2.1.2.6.5 VHF Ranging.—During manual sequencing, with P20 operating in the background, the crew initiates VHF ranging by keying VERB 87 ENTR on any flashing display of modes P30–P36 and P72–P75. To discontinue VHF ranging, the crew keys VERB 88 ENTR. In the MINKEY sequence, however, VHF ranging is initiated automatically (within 327.67 n.mi.) and, normally, continues throughout rendezvous. Should the crew, for any reason, wish to terminate VHF ranging, he would do so by keying VERB 88 ENTR—at any time.

> <u>NOTE.</u>—P20 estimate of range, based on state-vector extrapolation, may be in error. Consequently, VHF ranging may be initiated prematurely, with a resulting excessive-update display. See Restrictions and Limitations, paragraph 4.2.1.2.4.

4.2.1.2.6.6 Plane-change IMU Alignment.—Alignment presents no problem for an LM-active plane change, which is performed by the LM Z-axis RCS engines (no attitude rotation). Unless the change-plane component was quite small, however, a CSM-active maneuver would require rotating the X-axis normal to the orbital plane. To avoid gimbal lock, the manual-sequencing procedure (CSM-active) is to perform an IMU Realignment (P52), by pulse-torquing to a pseudo landing site of 45-deg latitude, immediately after exiting the targeting program. After realigning the IMU, the crew calls the Powered-flight Program (P40) to perform the attitude and translation maneuver. After completing the powered-flight program, the crew manually rotates the spacecraft X-axis back into plane, then performs an IMU Realignment (P52) by pulse-torquing to the actual landing site.

The MINKEY procedure for avoiding plane-change gimbal lock is to perform the following sequence, incorporating a modified P52:

1. A new REFSMMAT is computed for a Z-gyro torqued 45 deg.
2. Resulting gimbal angles are computed and displayed (VERB 06 NOUN 22) for a Z-gyro torqued 45 deg. Crew keys PRO.
3. VERB 50 NOUN 25 (R1 = 00020) request crew to, "Please perform MINKEY PC pulse torquing."
4. Crew keys PRO (CMC MODE switch in FREE), and the Z-gyro is pulse-torqued 45 deg. (An ENTR response bypasses pulse torquing and calls P41, then P76, and proceeds to next reset point.)

> <u>NOTE.</u>—Once PRO is keyed on the VERB 50 NOUN 25 display, the plane-change sequence must not be interrupted. Sequence must be allowed to complete in order to reestablish original IMU alignment.

5. During torquing, present gimbal angles are displayed by VERB 16 NOUN 20. At completion of torquing, the display blanks and P40/P41 is called.
6. After regular P40/P41, the CMC calls P76 to update the LM state vector and then calls P20 to perform automatic maneuver to tracking attitude.

> NOTE.—Should it become necessary to manually avoid gimbal lock during the maneuver back to the tracking attitude, the program will proceed to step 7, and the crew will have no display available (NOUN 18) for viewing the desired gimbal angles. Unless the original maneuver to burn attitude attempted to go through gimbal lock, however, the return maneuver to tracking attitude is not likely to require manual intervention. Should manual maneuvering be required, the crew can fly the spacecraft back into plane (referencing the FDAI Ball), then respond to the pulse-torquing request. When pulse torquing has completed, the program will proceed to the next reset point, and, if further maneuvering is necessary, the crew will be requested (FL VERB 50 NOUN 18) to perform a maneuver to tracking attitude.

7. When tracking attitude obtains, the program returns to the P52 subroutines and completes the first three of the above steps in order to reestablish the original alignment.
8. Crew keys PRO (CMC MODE switch in FREE), and the Z-gyro is pulse torqued to original alignment.

> NOTE.—An ENTR response here produces an Alarm 00402. Crew must perform pulse torquing.

9. During torquing, the present gimbal angles are displayed by VERB 16 NOUN 20. At completion of torquing, the display blanks, and program proceeds to next reset point.

4.2.1.2.6.7 LM-active, CMC Update of LM State Vector.—In manually sequenced rendezvous, the crew must call the Target-Δv Program (P76) and enter the LM's thrusting parameters in order to update the CMC's LM state vector every time the LM executes a thrusting maneuver. In MINKEY-sequenced rendezvous, however, the CMC calls P76 after each thrusting maneuver. If the command module's SPS

or RCS translational thrusters were used,* P76 will display a zero update; otherwise, the update will be as follows:

1. Post-HAM—LM state vector updated with (-) $\underline{v}_G$ (CSM) computed in P31—includes out of plane; (-) Y-dot$_{LM}$ used.
2. Post-CSI—LM state vector updated with (-) $\underline{v}_G$ (CSM) computed in P32—includes out of plane; (-) Y-dot$_{LM}$ used.
3. Post-PC—LM state vector updated with (-) Y-dot$_{LM}$ computed in P36.
4. Post-CDH—LM state vector updated with $\underline{v}_G$ (LM) computed by modified P73—includes out of plane; (-) Y-dot$_{LM}$ used.
5. Post-TPI—LM state vector updated by $\underline{v}_G$ (LM) computed by modified P74.
6. Post-MCC1 and 2—LM state vector updated by $\underline{v}_G$ (LM) computed by modified P75.

4.2.1.2.6.8 Procedures.—The DSKY procedures for MINKEY rendezvous are listed chronologically in Table 4.2.1-IV.

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*SPS thrusters are defined as "used" when a PRO response is given on the FL VERB 99 NOUN 40 display. —See Table 4.2.1-IV, step 12f (P40 Sequence). RCS translational thrusters are defined as "used" anytime the translational hand controller is removed from detent during AVERAGEG in P40/P41. There is a possibility, however, that the program will misinterpret the burn as LM-active if the THC is deflected for less than 2 sec. In that instance, it will be necessary to manually zero the P76 NOUN 84 display.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
1	Pre-HAM (V37E 31.)	FL V50 N25*	P31	Request permission to perform MINKEY Rendezvous.	R1 00017 option code R2 Blank R3 Blank	Start P20 Upon crew's PRO, start MINKEY Rendezvous Sequence. Upon crew's ENTR, proceed with conventional sequence.	PRO to effect MINKEY Rendezvous.	DAP Data Load Routine (R03) should be performed before targeting program is called. Preferred-tracking-attitude yaw and pitch (R1 and R2 of NOUN 78) automatically set to zero and -35 deg respectively; rotation (R3) automatically set to zero or 180 deg, depending upon HDSUPFLG. Crew can change contents of NOUN 78 if he chooses. *NOTE.—FL V50 N25 display occurs only once during MINKEY sequence, i.e., when first entered.
2		FL V50 N18**	P31	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to tracking attitude.	PRO	**Occurs only if $\Delta\theta > 10$ deg. V06 N18 occurs only if crew keys PRO on FL V50 N18.
3		V06 N18**	P31	Nonflashing display of final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude and begin navigation. Should MGA reach 75 deg, terminate maneuver and enter ATT HOLD.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03), when last performed. When tracking attitude is obtained, crew can begin taking SXT marks at its discretion. Navigation continues automatically until crew requests final targeting computation. VHF marks, automatic.
4		FL V06 N11	P31	Display t_{IG} (CSI).	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Accumulate VHF marks and perform navigation.	Check t_{IG} (CSI) against pad value; if correct, key PRO; if incorrect, key VERB 25 ENTR, load correct value, then key PRO.	If P31 is the first program called in the MINKEY sequence, the crew must load t_{IG} (CSI); if, however, P31 is entered from a multiple-CSI condition, the t_{IG} displayed here will be correct for the planned CSI at NN = 1.
5		FL V06 N55	P31	Display the future apsidal crossing (NN) of active vehicle when t_{IG} (CDH) should occur. Display the elevation angle (E) of the CSM-LM LOS above local horizontal at t_{IG} (TPI)—referenced to direction to flight. Display the orbital central angle (CENTANG) of the passive vehicle during the transfer from t_{IG} (TPI) to time of intercept.	R1 oooon NN R2 xxx.xx deg E R3 xxx.xx deg CENTANG	If register R3 contains value other than zero, compute a t_{IG} (CDH) for CSI -n (180 deg), where n is specified in R1. If register R3 contains zero, compute a t_{IG} (CDH) for CSI -n apsides.	If a t_{IG} (CDH) for CSI -n (180 deg) is desired, verify or load the appropriate values in R1, R2 and R3; then key PRO. Record values If apsidal t_{IG} (CDH) is desired, key V25E, load the desired n in register R1 and 00000 in register R3; then key PRO.	The value of CENTANG at this point is inconsequential except as an option code: 00000 denotes apsides option; all other denote CSI +n (180 deg) option.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
6		FL V06 N37	P31	Display t_{IG} (TPI).	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Accumulate VHF marks and perform navigation.	Check t_{IG} (TPI) against pad value: if correct, key PRO; if incorrect, key VERB 25 ENTR, load correct value, then key PRO.	
7		FL V06 N33	P31	Display t_{IG} (HAM).	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Accumulate VHF marks and perform navigation.	Record and key PRO.	t_{IG} (HAM) is computed and displayed based on t_{IG} (CSI -180 deg).
8		FL V16 N45	P31	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display code indicating final cycle has not been requested (PRO).	R1 xxBxx Marks {VHF (first two) SXT (last two)} R2 xxBxx TFI {min (first two) sec (last two)} R3 -00001 preliminary cycle	Perform navigation; recycle for preliminary targeting solution upon the crew's VERB 32 ENTR. Cease navigation, compute and display final targeting solution upon crew's PRO.	Take SXT marks and monitor TFI; key VERB 32 ENTR for preliminary targeting solution; key PRO to terminate navigation and to perform final targeting computation.	TFI (R2) indicates time remaining before t_{IG} (HAM). Request final targeting (PRO) when TFI ≈ -10 min.

RECYCLE SEQUENCE (VERB 32 ENTR RESPONSE TO FL VERB 16 NOUN 45)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
8a		FL V06 N90	P31	Display out-of-plane parameters.	R1 xxx.xx n.mi. Y CSM R2 xxxx.x ft/sec $\dot{Y}$ CSM R3 xxxx.x ft/sec $\dot{Y}$ LM	Accumulate marks. Overwrite R2 in N81 with (-) $\dot{Y}$ CSM.	Record PRO	
8b		FL V06 N81	P31	Display preliminary computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Accumulate marks.	Record PRO	
8c		FL V16 N45	P31	Display number of VHF and SXT marks accumulated since last WRI; display TFI.	R1 xxBxx VHF, SXT marks R2 xxBxx min, sec TFI R3 -00001 preliminary cycle	Perform navigation; recycle steps 8a-8c upon the crew's keying VERB 32 ENTR. Cease navigation, compute and display final targeting solution (steps 9-11) upon the crew's keying PRO.	Take SXT marks and monitor TFI; key VERB 32 ENTR for preliminary solution (recycle); key PRO to terminate navigation and to perform final targeting solution.	TFI (R2) indicates time remaining before t_{IG}. Request final targeting (PRO) when TFI ≈ -10 min.

FINAL SOLUTION SEQUENCE (PRO RESPONSE TO FL VERB 16 NOUN 45)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
9		FL V06 N90	P31	Display out-of-plane parameters.	R1 xxx.xx n.mi. Y CSM R2 xxxx.x ft/sec $\dot{Y}$ CSM R3 xxxx.x ft/sec $\dot{Y}$ LM	Overwrite R2 in N81 with (-) $\dot{Y}$ CSM.	Record PRO	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
10		FL V06 N81	P31	Display final-computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)		Record PRO	
11		FL V16 N45	P31	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display MGA at t_{IG}.	R1 xxBxx VHF, SXT R2 xxBxx min, sec TFI R3 xxx.xx deg MGA	- - -	Record PRO	If v_G is $\geq$ 7 ft/sec, program proceeds to P40 sequence; if v_G is < 7 ft/sec, program proceeds to P41 sequence.

P40 SEQUENCE ($v_G \geq 7$ ft/sec)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
12a		FL V50 N18	P40	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude.	PRO	
12b		V06 N18	P40	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to flashing V50 N18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.
12c		FL V50 N18	P40	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing V06 N18 display to return until trim maneuver has completed; then, FL V50 N18 returns. PRO again repeats the sequence; ENTR calls next step. The RHC can be used to establish wings level.
12d		FL V50 N25	P40	Request permission to perform gimbal drive test.	R1 00204 option code R2 Blank R3 Blank	Upon crew's PRO, perform gimbal drive test and then drive engine bell to trim position; upon crew's ENTR, inhibit drive test and drive engine bell to trim position.	PRO/ENTR Monitor gimbal drive test and gimbal drive to trim attitude.	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
12e		V06 N40	P40	Display TFI, velocity to be gained (v_G), and sum of acquired velocity (Δv_M).	R1 xxBxx min, sec TFI R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform normal P40 procedures. At t_{IG} -35 sec, display blanks for 5 sec, then returns.	Monitor Perform usual P40 duties, e.g., ullage.	
12f		FL V99 N40	P40	Request burn permission.	R1, R2, R3 Same as step 12e	Upon crew's PRO, begin SPS burn at t_{IG}; follow normal P40 procedures. Upon crew's ENTR, bypass burn and go to step 12i.	At t_{IG} -5 sec, key PRO/ENTR, depending upon whether CSM is active or passive.	If PRO is not keyed until after t_{IG}, ignition occurs on the PRO.
12g		V06 N40	P40	Nonflashing display of TFC, v_G, and Δv_M.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform burn.	Monitor	Normal P40. R1 indicates TFI until ignition, then TFC.
12h		FL V16 N40	P40	Indicate completion of burn.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Upon crew's PRO, proceed to FL V16 N85.	PRO	Normal P40.
12i		FL V16 N85	P40	Display remaining velocity to be gained.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Normal P40. Upon crew's PRO, proceed to step 13.	Trim out residual Δv (if applicable) and key PRO.	

P41 SEQUENCE (v_G < 7 ft/sec)

12a		FL V50 N18	P41	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude. Upon crew's ENTR, bypass attitude maneuver and proceed to step 12d.	PRO/ENTR.	
12b		V06 N18	P41	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to FL VERB 50 NOUN 18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
12c		FL V50 N18	P41	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing VERB 06 NOUN 18 display to return until trim maneuver has completed: then, FL VERB 50 NOUN 18 returns. PRO again repeats the sequence, ENTR calls next step. The RHC can be used to establish wings level.
12d		V06 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Update v_G display every 1 sec.	Monitor	DSKY blanks at t_{IG} -35 sec.
12e		V16 N85	P41	Display (nonflashing) velocity to be gained (v_G) in CSM control coordinates. Indicate that AVERAGEG is being performed.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	At TFI = -30 sec, start AVERAGEG and flash ACTY every 2 sec.	Monitor	
12f		FL V16 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates and indicate time of ignition (t_{IG}) by flashing.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Continue updating every 2 sec. Upon crew's PRO, proceed to step 13.	If CSM active, use hand controller to null three components of v_G, then key PRO. If CSM passive, key PRO.	
13		FL V06 N33	P76	Display t_{IG}.	R1 ooxxx. hr (GET) R2 oooxx. mm R3 oxx.xx sec	Upon crew's PRO, proceed to FL V06 N84.	If displayed t_{IG} is correct, key PRO; if displayed t_{IG} is not correct, key V25E, load correct t_{IG}, and then key PRO.	The t_{IG} displayed is the t_{IG} used by the previous targeting program.
14		FL V06 N84	P76	Display three components of Δv.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Upon crew's PRO, update LM state vector to reflect the added Δv.	If displayed Δv is correct, key PRO; if displayed Δv is not correct, key V25E, load correct values, and then key PRO.	If CSM performed maneuver, three components of Δv display will be zero; if LM performed maneuver, Δv components will be the (-) v_G CSM computed by the CSM targeting program. [including plane change (-) Y_{LM}]
15	Pre-CSI (V37E 32E)	FL V50 N25*	P32	Request permission to perform MINKEY Rendezvous.	R1 00017 option code R2 Blank R3 Blank	Start P20 Upon crew's PRO, start MINKEY Rendezvous Sequence. Upon crew's ENTR, proceed with conventional sequence.	PRO to effect MINKEY Rendezvous.	DAP Data Load Routine (R03) should be performed before targeting program is called. Preferred-tracking-attitude yaw and pitch (R1 and R2 of NOUN 78) automatically set to zero and -35 deg respectively; rotation (R3) automatically set to zero or 180 deg, depending upon HDSUPFLG. Crew can change contents of NOUN 78 if he chooses. *NOTE.—FL V50 N25 display occurs only if MINKEY sequence initiated at this reset point.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
16		FL V50 N18**	P32	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to tracking attitude.	PRO	**Occurs only if $\Delta\theta > 10$ deg. V06 N18 occurs only if crew keys PRO on FL V50 N18.
17		V06 N18**	P32	Nonflashing display of final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude and begin navigation. Should MGA reach 75 deg, terminate maneuver and enter ATT HOLD.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03), when last performed. When tracking attitude is obtained, crew can begin taking SXT marks at its discretion. Navigation continues automatically until crew requests final targeting computation. VHF marks, automatic.
18		FL V06 N11	P32	Display t_{IG} (CSI).	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Accumulate VHF marks and perform navigation.	Check t_{IG} (CSI) against pad value; if correct, key PRO; if incorrect, key VERB 25 ENTR, load correct value, then key PRO.	If P32 is the first program called in the MINKEY sequence, the crew must load t_{IG} (CSI); if, however, P32 is entered from a multiple-CSI condition, the t_{IG} displayed here will be correct for the upcoming CSI.
19		FL V06 N55	P32	Display the future apsidal crossing (NN) of active vehicle when t_{IG} (CDH) should occur. Display the elevation angle (E) of the CSM-LM LOS above local horizontal at t_{IG} (TPI)—referenced to direction to flight. Display the orbital central angle (CENTANG) of the passive vehicle during the transfer from t_{IG} (TPI) to time of intercept.	R1 ooooN. NN R2 xxx.xx deg E R3 xxx.xx deg CENTANG	Accumulate VHF marks and perform navigation. Upon crew's PRO, perform the following: If register R3 contains value other than zero, compute a t_{IG} (CDH) for CSI +n (180 deg), where n is specified in R1. If register R3 contains zero, compute a t_{IG} (CDH) for CSI +n apsides.	If a t_{IG} (CDH) for CSI -n (180 deg) is desired, verify or load the appropriate values in R1, R2 and R3; then key PRO, Record values If apsidal t_{IG} (CDH) is desired, key V25E, load the desired n in register R1 and 00000 in register R3; then key PRO.	The value of CENTANG at this point is unconsequential except as an option code; 00000 denotes apsides option; all other denote CSI +n (180 deg) option.
20		FL V06 N37	P32	Display t_{IG} (TPI).	R1 ooxxx. hr(GET) R2 oooxx. min R3 oxx.xx sec	Accumulate VHF marks and perform navigation.	Check t_{IG} (TPI) against pad value: if correct, key PRO; if incorrect, key VERB 25 ENTR, load correct value, then key PRO.	Take SXT marks at crew's discretion.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
21		FL V16 N45	P32	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display code indicating final cycle has not been requested (PRO).	R1 xxBxx Marks { VHF (first two), SXT (last two) } R2 xxBxx TFI { min (first two), sec (last two) } R3 -00001 preliminary cycle	Perform navigation; recycle for preliminary targeting solution upon the crew's VERB 32 ENTR. Cease navigation, compute and display final targeting solution upon crew's PRO.	Take SXT marks and monitor TFI; key VERB 32 ENTR for preliminary targeting solution; key PRO to terminate navigation and to perform final targeting computation.	TFI (R2) indicates time remaining before t_{IG}. Request final targeting (PRO) when TFI ≈ -10 min.

RECYCLE SEQUENCE (VERB 32 ENTR RESPONSE TO FL VERB 16 NOUN 45)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
21a		FL V06 N90	P32	Display out-of-plane parameters.	R1 xxx.xx n.mi. Y CSM R2 xxxx.x ft/sec $\dot{Y}$ CSM R3 xxxx.x ft/sec $\dot{Y}$ LM	Accumulate marks. Overwrite R2 in N81 with (-) $\dot{Y}$ CSM.	Record PRO	
21b		FL V06 N81	P32	Display preliminary computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Accumulate marks.	Record PRO	
21c		FL V16 N45	P32	Display number of VHF and SXT marks accumulated since last WRI; display TFI.	R1 xxBxx VHF, SXT marks R2 xxBxx min, sec TFI R3 -00001 preliminary cycle	Perform navigation; recycle steps 21a-21c upon the crew's keying VERB 32 ENTR. Cease navigation, compute and display final targeting solution (steps 22-24) upon the crew's keying PRO.	Take SXT marks and monitor TFI; key VERB 32 ENTR for preliminary solution (recycle); key PRO to terminate navigation and to perform final targeting solution.	TFI (R2) indicates time remaining before t_{IG}. Request final targeting (PRO) when TFI ≈ -10 min.

FINAL SOLUTION SEQUENCE (PRO RESPONSE TO FL VERB 16 NOUN 45)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
22		FL V06 N90	P32	Display out-of-plane parameters.	R1 xxx.xx n.mi. Y CSM R2 xxxx.x ft/sec $\dot{Y}$ CSM R3 xxxx.x ft/sec $\dot{Y}$ LM	Overwrite R2 in N81 with (-) $\dot{Y}$ CSM.	Record PRO	
23		FL V06 N81	P32	Display final-computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)		Record PRO	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
24		FL V16 N45	P32	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display MGA at t_{IG}.	R1 xxBxx VHF, SXT R2 xxBxx min, sec TFI R3 xxx.xx deg MGA	— — —	Record PRO	If v_G is ≥ 7 ft/sec, program proceeds to P40 sequence; if v_G is < 7 ft/sec, program proceeds to P41 sequence.

P40 SEQUENCE ($v_G \geq 7$ ft/sec)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
25a		FL V50 N18	P40	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude.	PRO	
25b		V06 N18	P40	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to flashing V50 N18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.
25c		FL V50 N18	P40	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing V06 N18 display to return until trim maneuver has completed; then, FL V50 N18 returns. PRO again repeats the sequence; ENTR calls next step. The RHC can be used to establish wings level.
25d		FL V50 N25	P40	Request permission to perform gimbal drive test.	R1 00204 option code R2 Blank R3 Blank	Upon crew's PRO, perform gimbal drive test and then drive engine bell to trim position; upon crew's ENTR, inhibit drive test and drive engine bell to trim position.	PRO/ENTR Monitor gimbal drive test and gimbal drive to trim attitude.	
25e		V06 N40	P40	Display TFI, velocity to be gained (v_G), and sum of acquired velocity (Δv_M).	R1 xxBxx min, sec TFI R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform normal P40 procedures. At t_{IG} -35 sec, display blanks for 5 sec, then returns.	Monitor Perform usual P40 duties, e.g., ullage.	
25f		FL V99 N40	P40	Request burn permission.	R1, R2, R3 Same as step 25e	Upon crew's PRO, begin SPS burn at t_{IG}; follow normal P40 procedures. Upon crew's ENTR, bypass burn and go to step 25i.	At t_{IG} -5 sec, key PRO/ENTR, depending upon whether CSM is active or passive.	If PRO is not keyed until after t_{IG}, ignition occurs on the PRO.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
25g		V06 N40	P40	Nonflashing display of TFC, v_G, and Δv_M.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform burn.	Monitor	Normal P40. R1 indicates TFI until ignition, then TFC.
25h		FL V16 N40	P40	Indicate completion of burn.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Upon crew's PRO, proceed to FL V16 N85.	PRO	Normal P40.
25i		FL V16 N85	P40	Display remaining velocity to be gained.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Normal P40. Upon crew's PRO, proceed to step 26.	Trim out residual Δv (if applicable) and key PRO.	

P41 SEQUENCE (v_G < 7 ft/sec)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
25a		FL V50 N18	P41	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude. Upon crew's ENTR, bypass attitude maneuver and proceed to step 25d.	PRO/ENTR.	
25b		V06 N18	P41	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles: if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to FL VERB 50 NOUN 18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.
25c		FL V50 N18	P41	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing VERB 06 NOUN 18 display to return until trim maneuver has completed; then, FL VERB 50 NOUN 18 returns. PRO again repeats the sequence, ENTR calls next step. The RHC can be used to establish wings level.
25d		V06 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Update v_G display every 1 sec.	Monitor	DSKY blanks at t_{IG} -35 sec.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
25e		V16 N85	P41	Display (nonflashing) velocity to be gained (v_G) in CSM control coordinates. Indicate that AVERAGEG is being performed.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	At TFI = -30 sec, start AVERAGEG and flash ACTY every 2 sec.	Monitor	
25f		FL V16 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates and indicate time of ignition (t_{IG}) by flashing.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Continue updating every 2 sec. Upon crew's PRO, proceed to step 26.	If CSM active, use hand controller to null three components of v_G, then key PRO. If CSM passive, key PRO.	
26		FL V06 N33	P76	Display t_{IG}.	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Upon crew's PRO, proceed to FL V06 N84.	If displayed t_{IG} is correct, key PRO; if displayed t_{IG} is not correct, key V25E, load correct t_{IG}, and then key PRO.	The t_{IG} displayed is the t_{IG} used by the previous targeting program.
27		FL V06 N84	P76	Display three components of Δv.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	If NN (R1, NOUN 55) = 4, return to step 2. If NN > 4, return to step 16; if NN < 4, proceed to step 29.	If displayed Δv is correct, key PRO; if displayed Δv is not correct, key V25E, load correct values, and then key PRO.	If CSM performed maneuver, three components of Δv display will be zero; if LM performed maneuver, Δv components will be the (-) v_G (CSM) computed by the CSM targeting program including plane change $\dot{Y}_{LM}$.
28	Pre-Plane Change (V37E 36E)	FL V50 N25*	P36	Request permission to perform MINKEY Rendezvous.	R1 00017 option code R2 Blank R3 Blank	Start P20 Upon crew's PRO, start MINKEY Rendezvous Sequence. Upon crew's ENTR, proceed with conventional sequence.	PRO to effect MINKEY Rendezvous.	DAP Data Load Routine (R03) should be performed before targeting program is called. Preferred-tracking-attitude yaw and pitch (R1 and R2 of NOUN 78) automatically set to zero and -35 deg respectively; rotation (R3) automatically set to zero or 180 deg, depending upon HDSUPFLG. Crew can change contents of NOUN 78 if he chooses. *NOTE.—FL V50 N25 display occurs only if MINKEY sequence initiated at this reset point.
29		FL V50 N18**	P36	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to tracking attitude.	PRO	**Occurs only if $\Delta\psi$ >10 deg. V06 N18 occurs only if crew keys PRO on FL V50 N18.
30		V06 N18**	P36	Nonflashing display of final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude and begin navigation. Should MGA reach 75 deg, terminate maneuver and enter ATT HOLD.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03), when last performed. When tracking attitude is obtained, crew can begin taking SXT marks at its discretion. Navigation continues automatically until crew requests final targeting computation. VHF marks, automatic.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
31		FL V06 N33	P36	Display t_{IG} (PC)	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Accumulate VHF marks and perform navigation.	Record and key PRO.	Computed from CSM state vector to occur 90 deg after CSI.
32		FL V16 N45	P36	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display code indicating final cycle has not been requested (PRO).	R1 xxBxx Marks {VHF (first two) SXT (last two) R2 xxBxx TFI {min (first two) sec (last two) R3 -00001 preliminary cycle	Perform navigation; recycle for preliminary targeting solution upon the crew's VERB 32 ENTR. Cease navigation, compute and display final targeting solution upon crew's PRO.	Take SXT marks and monitor TFI; key VERB 32 ENTR for preliminary targeting solution; key PRO to terminate navigation and to perform final targeting computation.	TFI (R2) indicates time remaining before t_{IG}. Request final targeting (PRO) when TFI ≈ -10 min.

RECYCLE SEQUENCE (VERB 32 ENTR RESPONSE TO FL VERB 16 NOUN 45)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
32a		FL V06 N90	P36	Display out-of-plane parameters.	R1xxx.xx n.mi. Y CSM R2 xxxx.x ft/sec $\dot{Y}$ CSM R3 xxxx.x ft/sec $\dot{Y}$ LM	Accumulate marks. Overwrite R2 in N81 with (-) $\dot{Y}$ CSM.	Record PRO	
32b		FL V06 N81	P36	Display preliminary computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Accumulate marks.	Record PRO	
32c		FL V16 N45	P36	Display number of VHF and SXT marks accumulated since last WRI; display TFI.	R1 xxBxx VHF, SXT marks R2 xxBxx min, sec TFI R3 -00001 preliminary cycle	Perform navigation; recycle steps 32a-32c upon the crew's keying VERB 32 ENTR. Cease navigation, compute and display final targeting solution (steps 33-35) upon the crew's keying PRO.	Take SXT marks and monitor TFI; key VERB 32 ENTR for preliminary solution (recycle); key PRO to terminate navigation and to perform final targeting solution.	TFI (R2) indicates time remaining before t_{IG}. Request final targeting (PRO) when TFI ≈ -10 min.

FINAL SOLUTION SEQUENCE (PRO RESPONSE TO FL VERB 16 NOUN 45)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
33		FL V06 N90	P36	Display out-of-plane parameters.	R1 xxx.xx n.mi. Y CSM R2 xxxx.x ft/sec $\dot{Y}$ CSM R3 xxxx.x ft/sec $\dot{Y}$ LM	Overwrite R2 in N81 with (-) $\dot{Y}$ CSM.	Record PRO	
34		FL V06 N81	P36	Display final-computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)		Record PRO	Load zero in R2 if no PC maneuver is desired. This may cause a 01301 alarm (arc sine-arc cosine argument too large) at the FL V16 N45 display. To recover, key RSET. PRO on FL V16 N45 bypasses maneuver and MINKEY proceeds to Plane Change Sequence III.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
35		FL V16 N45	P36	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display MGA at t_{IG}.	R1 xxBxx VHF, SXT R2 xxBxx min, sec TFI R3 xxx.xx deg MGA	– – –	Record PRO	PRO calls PC Sequence I or III.

PLANE CHANGE SEQUENCE I: $v_G \neq 0$ (Perform Plane-change Alignment)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
36a		FL V06 N22	P52	Display gimbal angles resulting from proposed IMU alignment.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Wait for crew response; terminate flash upon receiving PRO; proceed to V50 N25.	Key PRO. (MGA should be approximately ±45 deg).	Sequence I: establishes an IMU alignment that will be acceptable when the spacecraft X-axis rotates 90 deg to the orbital plane; (2) performs a thrusting maneuver to null the out-of-plane velocity and calls P76 to update the CMC's LM state vector; (3) reorients spacecraft to tracking attitude; (4) re-establishes the original IMU alignment.
36b		FL V50 N25	P52	Request permission to perform plane-change alignment.	R1 00020 R2 Blank R3 Blank	Upon crew's PRO, pulse torque Z-gyro 45 deg (requires 1-1/2 min). Upon crew's ENTR, omit PC alignment and proceed to Sequence II.	To prevent the S/C from rotating as the gyros are being torqued, select DAP FREE Mode and then key PRO to perform the pulse-torque option. To omit PC alignment, key ENTR.	
36c		V16 N20	P52	Display gimbal angles during gyro torquing.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform gyro torquing. Display blanks when torquing has finished; P40/P41 is called automatically.	Monitor DSKY. If MGA approaches gimbal lock, use rotational hand controller to avoid the condition.	It is not necessary to maintain a fixed spacecraft orientation during torquing.

P40 SEQUENCE ($v_G \geq 7$ ft/sec)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
36d1		FL V50 N18	P40	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude.	PRO	
36d2		V06 N18	P40	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to flashing V50 N18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
36d3		FL V50 N18	P40	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing V06 N18 display to return until trim maneuver has completed; then, FL V50 N18 returns. PRO again repeats the sequence; ENTR calls next step. The RHC can be used to establish wings level.
36d4		FL V50 N25	P40	Request permission to perform gimbal drive test.	R1 00204 option code R2 Blank R3 Blank	Upon crew's PRO, perform gimbal drive test and then drive engine bell to trim position; upon crew's ENTR, inhibit drive test and drive engine bell to trim position.	PRO/ENTR Monitor gimbal drive test and gimbal drive to trim attitude.	
36d5		V06 N40	P40	Display TFI, velocity to be gained (v_G), and sum of acquired velocity (Δv_M).	R1 xxBxx min, sec TFI R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform normal P40 procedures. At t_{IG} -35 sec, display blanks for 5 sec, then returns.	Monitor Perform usual P40 duties, e.g., ullage.	
36d6		FL V99 N40	P40	Request burn permission.	R1, R2, R3: Same as step 36d5	Upon crew's PRO, begin SPS burn at t_{IG}; follow normal P40 procedures. Upon crew's ENTR, bypass burn and go to step 36d9.	At t_{IG} -5 sec, key PRO/ENTR, depending upon whether CSM is active or passive.	If PRO is not keyed until after t_{IG}, ignition occurs on the PRO.
36d7		V06 N40	P40	Nonflashing display of TFC, v_G, and Δv_M.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform burn.	Monitor	Normal P40. R1 indicates TFI until ignition, then TFC.
36d8		FL V16 N40	P40	Indicate completion of burn.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Upon crew's PRO, proceed to FL V16 N85.	PRO	Normal P40.
36d9		FL V16 N85	P40	Display remaining velocity to be gained.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Normal P40. Upon crew's PRO, proceed to step 36e.	Trim out residual Δv (if applicable) and key PRO.	

P41 SEQUENCE ($v_G < 7$ ft/sec)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
36d1		FL V50 N18	P41	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude. Upon crew's ENTR, bypass attitude maneuver and proceed to step 36d4.	PRO/ENTR.	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
36d2		V06 N18	P41	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to FL VERB 50 NOUN 18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.
36d3		FL V50 N18	P41	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing VERB 06 NOUN 18 display to return until trim maneuver has completed; then, FL VERB 50 NOUN 18 returns. PRO again repeats the sequence, ENTR calls next step. The RHC can be used to establish wings level.
36d4		V06 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Update v_G display every 1 sec.	Monitor	DSKY blanks at t_{IG} -35 sec.
36d5		V16 N85	P41	Display (nonflashing) velocity to be gained (v_G) in CSM control coordinates. Indicate that AVERAGEG is being performed.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	At TFI = -30 sec, start AVERAGEG and flash ACTY every 2 sec.	Monitor	
36d6		FL V16 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates and indicate time of ignition (t_{IG}) by flashing.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Continue updating every 2 sec. Upon crew's PRO, proceed to next step.	If CSM active, use hand controller to null three components of v_G, then key PRO. If CSM passive, key PRO.	
36e		FL V06 N33	P76	Display t_{IG}.	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Upon crew's PRO, proceed to FL V06 N84.	If displayed t_{IG} is correct, key PRO; if displayed t_{IG} is not correct, key V25E, load correct t_{IG}, and then key PRO.	The t_{IG} displayed is the t_{IG} used by the previous targeting program.
36f		FL V06 N84	P76	Display three components of Δv.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Upon crew's PRO, update LM state vector to reflect the added Δv[including plane change, (-) $\dot{Y}_{LM}$]	If displayed Δv is correct, key PRO; if displayed Δv is not correct, key V25E, load correct values, and then key PRO.	If CSM performed maneuver, three components of Δv display will be zero; if LM performed maneuver, Δv components will be the(-)v_G (CSM) computed by the CSM targeting program including plane change -$\dot{Y}_{LM}$.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
36g		FL V50 N18	P20	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to tracking attitude.	PRO	
36h		V06 N18	P20	Nonflashing display of final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude and begin navigation. Should MGA reach 75 deg, terminate maneuver and enter ATT HOLD.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03), when last performed. If maneuver is interrupted, program will proceed immediately to step 36i. Crew must maneuver S/C back into plane by referencing the FDAI Ball.
36i		FL V06 N22	P52	Display gimbal angles resulting from proposed IMU alignment.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Wait for crew response; terminate flash upon receiving PRO; proceed to V50 N25.	Key PRO. (MGA should be approximately ±45 deg).	
36j		FL V50 N25	P52	Request permission to perform in-plane alignment.	R1 00020 R2 Blank R3 Blank	Upon crew's PRO, pulse torque Z-gyro 45 deg (requires 1-1/2 min).	To prevent the S/C from rotating as the gyros are being torqued, select DAP FREE Mode and then key PRO to perform the pulse-torque option.	An ENTR here causes an Alarm 00402. Crew must perform pulse torquing.
36k		V16 N20	P52	Display gimbal angles during gyro torquing.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform gyro torquing. Display blanks when torquing has finished; program proceeds to next reset point (step 38).	Monitor DSKY. If MGA approaches gimbal lock, use rotational hand controller to avoid the condition.	It is not necessary to maintain a fixed spacecraft orientation during torquing.

PLANE CHANGE SEQUENCE II: $V_G \neq 0$ (Omit Plane-change Alignment)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
36a1		FL V50 N18	P41	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude. Upon crew's ENTR, bypass attitude maneuver and proceed to step 36a4.	PRO/ENTR.	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
36a2		V06 N18	P41	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to FL VERB 50 NOUN 18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.
36a3		FL V50 N18	P41	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing VERB 06 NOUN 18 display to return until trim maneuver has completed; then, FL VERB 50 NOUN 18 returns. PRO again repeats the sequence, ENTR calls next step. The RHC can be used to establish wings level.
36a4		V06 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Update v_G display every 1 sec.	Monitor	DSKY blanks at t_{IG} -35 sec.
36a5		V16 N85	P41	Display (nonflashing) velocity to be gained (v_G) in CSM control coordinates. Indicate that AVERAGEG is being performed.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	At TFI = -30 sec, start AVERAGEG and flash ACTY every 2 sec.	Monitor	
36a6		FL V16 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates and indicate time of ignition (t_{IG}) by flashing.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Continue updating every 2 sec. Upon crew's PRO, proceed to next step	If CSM active, use hand controller to null three components of v_G, then key PRO. If CSM passive, key PRO.	
36b		FL V06 N33	P76	Display t_{IG}.	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Upon crew's PRO, proceed to FL V06 N84.	If displayed t_{IG} is correct, key PRO; if displayed t_{IG} is not correct, key V25E, load correct t_{IG}, and then key PRO.	The t_{IG} displayed is the t_{IG} used by the previous targeting program.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry P...	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
36c		FL V06 N84	P76	Display three components of Δv.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Upon crew's PRO, update LM state vector to reflect the added Δv [including plane change, $(-) Y_{LM}$] Proceed to step 38	If displayed Δv is correct, key PRO; if displayed Δv is not correct, key V25E, load correct values, and then key PRO.	If CSM performed maneuver, three components of Δv display will be zero; if LM performed maneuver, Δv components will be the $(-) v_G$ (CSM) computed by the CSM targeting program including plane change $(-) Y_{LM}$.
PLANE CHANGE SEQUENCE III: $v_G = 0$								
36a		FL V06 N33	P76	Display t_{IG}.	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Upon crew's PRO, proceed to FL V06 N84.	If displayed t_{IG} is correct, key PRO; if displayed t_{IG} is not correct, key V25E, load correct t_{IG}, and then key PRO.	The t_{IG} displayed is the t_{IG} used by the previous targeting program.
36b		FL V06 N84	P76	Display three components of Δv.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Upon crew's PRO, update LM state vector to reflect the added Δv Proceed to step 38.	If displayed Δv is correct, key PRO; if displayed Δv is not correct, key V25E, load correct values, and then key PRO.	
37	Pre-CDH (V37E 33E)	FL V50 N25*	P33	Request permission to perform MINKEY Rendezvous.	R1 00017 option code R2 Blank R3 Blank	Start P20 Upon crew's PRO, start MINKEY Rendezvous Sequence. Upon crew's ENTR, proceed with conventional sequence.	PRO to effect MINKEY Rendezvous.	DAP Data Load Routine (R03) should be performed before targeting program is called. Preferred-tracking-attitude yaw and pitch (R1 and R2 of NOUN 78) automatically set to zero and -35 deg respectively; rotation (R3) automatically set to zero or 180 deg, depending upon HDSUPFLG. Crew can change contents of NOUN 78 if he chooses. *NOTE.—FL V50 N25 display occurs only if MINKEY sequence initiated at this reset point.
38		FL V50 N18**	P33	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to tracking attitude.	PRO	**Occurs only if $\Delta\theta > 10$ deg. V06 N18 occurs only if crew keys PRO on FL V50 N18.
39		V06 N18**	P33	Nonflashing display of final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude and begin navigation. Should MGA reach 75 deg, terminate maneuver and enter ATT HOLD.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03), when last performed. When tracking attitude is obtained, crew can begin taking SXT marks at its discretion. Navigation continues automatically until crew requests final targeting computation. VHF marks, automatic.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
40		FL V06 N13	P33	Display t_{IG} (CDH).	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Accumulate VHF marks and perform navigation.	Record and key PRO.	NOUN 13 is calculated from P32 input values.
41		FL V16 N45	P33	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display code indicating final cycle has not been requested (PRO).	R1 xxBxx Marks { VHF (first two) SXT (last two) } R2 xxBxx TFI { min (first two) sec (last two) } R3 -00001 preliminary cycle	Perform navigation; recycle for preliminary targeting solution upon the crew's VERB 32 ENTR. Cease navigation, compute and display final targeting solution upon crew's PRO.	Take SXT marks and monitor TFI; key VERB 32 ENTR for preliminary targeting solution; key PRO to terminate navigation and to perform final targeting computation.	TFI (R2) indicates time remaining before t_{IG}. Request final targeting (PRO) when TFI ≈ -10 min.

RECYCLE SEQUENCE (VERB 32 ENTR RESPONSE TO FL VERB 16 NOUN 45)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
41a		FL V06 N90	P33	Display out-of-plane parameters.	R1 xxx.xx n.mi. Y CSM R2 xxxx.x ft/sec $\dot{Y}$ CSM R3 xxxx.x ft/sec $\dot{Y}$ LM	Accumulate marks. Overwrite R2 in N81 with (-) $\dot{Y}$ CSM.	Record PRO	
41b		FL V06 N81	P33	Display preliminary computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Accumulate marks.	Record PRO	
41c		FL V16 N45	P33	Display number of VHF and SXT marks accumulated since last WRI; display TFI.	R1 xxBxx VHF, SXT marks R2 xxBxx min, sec TFI R3 -00001 preliminary cycle	Perform navigation; recycle steps 41a-41c upon the crew's keying VERB 32 ENTR. Cease navigation, compute and display final targeting solution (steps 42-44) upon the crew's keying PRO.	Take SXT marks and monitor TFI; key VERB 32 ENTR for preliminary solution (recycle); key PRO to terminate navigation and to perform final targeting solution.	TFI (R2) indicates time remaining before t_{IG}. Request final targeting (PRO) when TFI ≈ -10 min.

FINAL SOLUTION SEQUENCE (PRO RESPONSE TO FL VERB 16 NOUN 45)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
42		FL V06 N90	P33	Display out-of-plane parameters.	R1 xxx.xx n.mi. Y CSM R2 xxxx.x ft/sec $\dot{Y}$ CSM R3 xxxx.x ft/sec $\dot{Y}$ LM	Overwrite R2 in N81 with (-) $\dot{Y}$ CSM.	Record PRO	
43		FL V06 N81	P33	Display final-computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)		Record PRO	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
44		FL V16 N45	P33	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display MGA at t_{IG}.	R1 xxBxx VHF, SXT R2 xxBxx min, sec TFI R3 xxx.xx deg MGA	- - -	Record PRO	If v_G is ≥ 7 ft/sec, program proceeds to P40 sequence; if v_G is < 7 ft/sec, program proceeds to P41 sequence.

P40 SEQUENCE ($v_G \geq 7$ ft/sec)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
45a		FL V50 N18	P40	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude.	PRO	
45b		V06 N18	P40	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to flashing V50 N18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.
45c		FL V50 N18	P40	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing V06 N18 display to return until trim maneuver has completed; then, FL V50 N18 returns. PRO again repeats the sequence; ENTR calls next step. The RHC can be used to establish wings level.
45d		FL V50 N25	P40	Request permission to perform gimbal drive test.	R1 00204 option code R2 Blank R3 Blank	Upon crew's PRO, perform gimbal drive test and then drive engine bell to trim position; upon crew's ENTR, inhibit drive test and drive engine bell to trim position.	PRO/ENTR Monitor gimbal drive test and gimbal drive to trim attitude.	
45e		V06 N40	P40	Display TFI, velocity to be gained (v_G), and sum of acquired velocity (Δv_M).	R1 xxBxx min, sec TFI R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform normal P40 procedures. At t_{IG} -35 sec, display blanks for 5 sec, then returns.	Monitor Perform usual P40 duties, e.g., ullage.	
45f		FL V99 N40	P40	Request burn permission.	R1, R2, R3 Same as step 45e	Upon crew's PRO, begin SPS burn at t_{IG}; follow normal P40 procedures. Upon crew's ENTR, bypass burn and go to step 45i.	At t_{IG} -5 sec, key PRO/ENTR, depending upon whether CSM is active or passive.	If PRO is not keyed until after t_{IG}, ignition occurs on the PRO.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
45g		V06 N40	P40	Nonflashing display of TFC, v_G, and Δv_M.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform burn.	Monitor	Normal P40. R1 indicates TFI until ignition, then TFC.
45h		FL V16 N40	P40	Indicate completion of burn.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Upon crew's PRO, proceed to FL V16 N85.	PRO	Normal P40.
45i		FL V16 N85	P40	Display remaining velocity to be gained.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Normal P40. Upon crew's PRO, proceed to step 46.	Trim out residual Δv (if applicable) and key PRO.	

P41 SEQUENCE (v_G < 7 ft/sec)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
45a		FL V50 N18	P41	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude. Upon crew's ENTR, bypass attitude maneuver and proceed to step 45d.	PRO/ENTR.	
45b		V06 N18	P41	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to FL VERB 50 NOUN 18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.
45c		FL V50 N18	P41	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing VERB 06 NOUN 18 display to return until trim maneuver has completed; then, FL VERB 50 NOUN 18 returns. PRO again repeats the sequence, ENTR calls next step. The RHC can be used to establish wings level.
45d		V06 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Update v_G display every 1 sec.	Monitor	DSKY blanks at t_{IG} -35 sec.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
45e		V16 N85	P41	Display (nonflashing) velocity to be gained (v_G) in CSM control coordinates. Indicate that AVERAGEG is being performed.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	At TFI = -30 sec, start AVERAGEG and flash ACTY every 2 sec.	Monitor	
45f		FL V16 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates and indicate time of ignition (t_{IG}) by flashing.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Continue updating every 2 sec. Upon crew's PRO, proceed to step 46.	If CSM active, use hand controller to null three components of v_G, then key PRO. If CSM passive, key PRO.	
46		FL V06 N33	P76	Display t_{IG}.	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Upon crew's PRO, proceed to FL V06 N84.	If displayed t_{IG} is correct, key PRO; if displayed t_{IG} is not correct, key V25E, load correct t_{IG}, and then key PRO.	The t_{IG} displayed is the t_{IG} used by the previous targeting program.
47		FL V06 N84	P76	Display three components of Δv.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Upon crew's PRO, update LM state vector to reflect the added Δv [including plane change, (-) $\dot{Y}_{LM}$]	If displayed Δv is correct, key PRO; if displayed Δv is not correct, key V25E, load correct values, and then key PRO.	If CSM performed maneuver, three components of Δv display will be zero; if LM performed maneuver, Δv components will be the v_G (LM) computed by the CSM program.
48	Pre-TPI (V37E 34E)	FL V50 N25*	P34	Request permission to perform MINKEY Rendezvous.	R1 00017 option code R2 Blank R3 Blank	Start P20 Upon crew's PRO, start MINKEY Rendezvous Sequence. Upon crew's ENTR, proceed with conventional sequence.	PRO to effect MINKEY Rendezvous.	DAP Data Load Routine (R03) should be performed before targeting program is called. Preferred-tracking-attitude yaw and pitch (R1 and R2 of NOUN 78) automatically set to zero and -35 deg respectively; rotation (R3) automatically set to zero or 180 deg, depending upon HDSUPFLG. Crew can change contents of NOUN 78 if he chooses. *NOTE.—FL V50 N25 display occurs only if MINKEY sequence initiated at this reset point.
49		FL V50 N18**	P34	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to tracking attitude.	PRO	**Occurs only if $\Delta\theta$ > 10 deg. V06 N18 occurs only if crew keys PRO on FL V50 N18.
50		V06 N18**	P34	Nonflashing display of final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude and begin navigation. Should MGA reach 75 deg, terminate maneuver and enter ATT HOLD.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03), when last performed. When tracking attitude is obtained, crew can begin taking SXT marks at its discretion. Navigation continues automatically until crew requests final targeting computation. VHF marks, automatic.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
51		FL V06 N37	P34	Display t_{IG} (TPI).	R1 ooxxx. hr(GET) R2 oooxx. min R3 oxx.xx sec	Accumulate VHF marks and perform rendezvous navigation.	Check t_{IG} (TPI) against pad value; if correct, key PRO; if incorrect, key VERB 25 ENTR, load correct value then key PRO.	The pad value of t_{IG} (TPI) should be loaded whether or not t_{IG}-computed option is to be used; otherwise an Alarm 611 may occur.
52		FL V06 N55	P34	Display the elevation angle (E) of the CSM-LM LOS above local horizontal at t_{IG} (TPI)—referenced to direction of flight. Display the orbital central angle (CENTANG) of the passive vehicle during the transfer from t_{IG} (TPI) to time of intercept.	R1 00000 R2 xxx.xx deg E R3 xxx.xx deg CENTANG	If register R2 contains value other than zero, compute a t_{IG} (TPI) based on the angle displayed. If register R2 contains zero, compute E based on t_{IG} (TPI) displayed in N37.	Record values. If t_{IG}-computed option is desired, verify that pad value of E is loaded in R2. If E-computed option is desired, verify that R2 contains 00000.	
53		FL V16 N45	P34	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display code indicating final cycle has not been requested (PRO).	R1 xxBxx Marks { VHF (first two) SXT (last two) } R2 xxBxx TFI { min (first two) sec (last two) } R3 -00001 preliminary cycle	Perform navigation; recycle for preliminary targeting solution upon the crew's VERB 32 ENTR. Cease navigation, compute and display final targeting solution upon crew's PRO.	VERB 32 ENTR (Recycle).	Recycle as often as desired. If either VHF or optics not operating, key VERB 57 ENTR and load R2 of NOUN 12 with 00001 (FULTKRFLG set) before entering P35. Depending upon value contained in R2 of NOUN 55, perform recycle Sequence I or II.

RECYCLE SEQUENCE I: REGISTER R2 OF NOUN 55 CONTAINS OTHER THAN ZERO (t_{IG}-computed option)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
53a		FL V06 N37	P34	Display computed t_{IG} (TPI).	R1 ooxxx. hr(GET) R2 oooxx. min R3 oxx.xx sec		Record PRO	
53b		FL V06 N58	P34	Display post-TPI perigee altitude, the TPI Δv, and the TPF Δv.	R1 xxxx.x n.mi. perigee altitude R2 xxxx.x ft/sec TPI Δv R3 xxxx.x ft/sec TPF Δv	— — —	Record PRO	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
53c		FL V06 N81	P34	Display final-computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Accumulate marks.	Record PRO	

RECYCLE SEQUENCE II: REGISTER R2 OF NOUN 55 (of step 52) CONTAINS 00000 (E-computed option)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
53a		FL V06 N55	P34	Display computed E for N37 t_{IG}.	R1 00000 R2 xxx.xx deg E R3 xxx.xx deg CENTANG		Record PRO	
53b		FL V06 N58	P34	Display post-TPI perigee altitude, the TPI Δv, and the TPF Δv.	R1 xxxx.x n.mi. perigee altitude R2 xxxx.x ft/sec TPI Δv R3 xxxx.x ft/sec TPF Δv	– – –	Record PRO	
53c		FL V06 N81	P34	Display final-computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Accumulate marks.	Record PRO	
54		FL V16 N45	P34	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display code indicating final cycle has not been requested (PRO).	R1 xxBxx Marks {VHF (first two), SXT (last two)} R2 xxBxx TFI {min (first two), sec (last two)} R3 -00001 preliminary cycle	Upon crew's PRO, cease navigation and compute final solution.	PRO	TFI (N45 R2) indicates time remaining before t_{IG} (TPI). When TFI ≈ -10 min, key PRO for Final Solution Sequence I or II, depending upon contents of NOUN 55.

FINAL-SOLUTION SEQUENCE I: REGISTER R2 OF NOUN 55 (of step 52) CONTAINS OTHER THAN ZERO (t_{IG}-computed option)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
54a		FL V06 N37	P34	Display computed t_{IG} (TPI).	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec		If CSM active, key PRO; if CSM passive, key VERB 25 ENTR, load LM's t_{IG} (TPI), then PRO.	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
54b		FL V06 N55	P34	Display computed E for N37 t_{IG}.	R1 00000 R2 xxx.xx deg E R3 xxx.xx deg CENTANG		Record PRO	Register R2 displays computed E based on N37 t_{IG} (step No. 54a).
54c		FL V06 N58	P34	Display post-TPI perigee altitude, the TPI Δv, and the TPF Δv.	R1 xxxx.x n.mi. perigee altitude R2 xxxx.x ft/sec TPI Δv R3 xxxx.x ft/sec TPF Δv	– – –	Record PRO	
54d		FL V06 N81	P34	Display final-computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)		Record PRO	
54e		FL V16 N45	P34	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display MGA at t_{IG}.	R1 xxBxx VHF, SXT R2 xxBxx min, sec TFI R3 xxx.xx deg MGA	Upon crew's PRO, proceed to powered-flight program.	Record PRO	If v_G is ≥ 7 ft/sec, program proceeds to P40 sequence; if v_G is < 7 ft/sec, program proceeds to P41 sequence.

FINAL-SOLUTION SEQUENCE II: REGISTER R2 OF NOUN 55 (of step 52) CONTAINS 00000 (E-computed option)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
54a		FL V06 N55	P34	Display computed E for N37 t_{IG}.	R1 00000 R2 xxx.xx deg E R3 xxx.xx deg CENTANG		Record PRO	
54b		FL V06 N58	P34	Display post-TPI perigee altitude, the TPI Δv, and the TPF Δv.	R1 xxxx.x n.mi. perigee altitude R2 xxxx.x ft/sec TPI Δv R3 xxxx.x ft/sec TPF Δv	– – –	Record PRO	
54c		FL V06 N81	P34	Display final-computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)		Record PRO	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
54d		FL V16 N45	P34	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display MGA at t_{IG}.	R1 xxBxx VHF, SXT R2 xxBxx min, sec TFI R3 xxx.xx deg MGA	Upon crew's PRO, proceed to powered-flight program.	Record PRO	If v_G is ≥ 7 ft/sec, program proceeds to P40 sequence; if v_G is < 7 ft/sec, program proceeds to P41 sequence.

P40 SEQUENCE ($v_G \geq 7$ ft/sec)

55a		FL V50 N18	P40	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude.	PRO	
55b		V06 N18	P40	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to flashing V50 N18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.
55c		FL V50 N18	P40	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing V06 N18 display to return until trim maneuver has completed; then, FL V50 N18 returns. PRO again repeats the sequence; ENTR calls next step. The RHC can be used to establish wings level.
55d		FL V50 N25	P40	Request permission to perform gimbal drive test.	R1 00204 option code R2 Blank R3 Blank	Upon crew's PRO, perform gimbal drive test and then drive engine bell to trim position; upon crew's ENTR, inhibit drive test and drive engine bell to trim position.	PRO/ENTR Monitor gimbal drive test and gimbal drive to trim attitude.	
55e		V06 N40	P40	Display TFI, velocity to be gained (v_G), and sum of acquired velocity (Δv_M).	R1 xxBxx min, sec TFI R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform normal P40 procedures. At t_{IG} -35 sec, display blanks for 5 sec, then returns.	Monitor Perform usual P40 duties, e.g., ullage.	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
55f		FL V99 N40	P40	Request burn permission.	R1, R2, R3: Same as step 55e	Upon crew's PRO, begin SPS burn at t_{IG}; follow normal P40 procedures. Upon crew's ENTR, bypass burn and go to step 55i.	At t_{IG} -5 sec, key PRO/ENTR, depending upon whether CSM is active or passive.	If PRO is not keyed until after t_{IG}, ignition occurs on the PRO.
55g		V06 N40	P40	Nonflashing display of TFC, v_G, and Δv_M.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform burn.	Monitor	Normal P40. R1 indicates TFI until ignition, then TFC.
55h		FL V16 N40	P40	Indicate completion of burn.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Upon crew's PRO, proceed to FL V16 N85.	PRO	Normal P40.
55i		FL V16 N85	P40	Display remaining velocity to be gained.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Normal P40. Upon crew's PRO, proceed to step 56.	Trim out residual Δv (if applicable) and key PRO.	
56		FL V06 N33	P76	Display t_{IG}.	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Upon crew's PRO, proceed to FL V06 N84.	If displayed t_{IG} is correct, key PRO; if displayed t_{IG} is not correct, key V25E, load correct t_{IG}, and then key PRO.	The t_{IG} displayed is the t_{IG} used by the previous targeting program.
57		FL V06 N84	P76	Display three components of Δv.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Upon crew's PRO, update LM state vector to reflect the added Δv.	If displayed Δv is correct, key PRO; if displayed Δv is not correct, key V25E, load correct values, and then key PRO.	If CSM performed maneuver, three components of Δv display will be zero; if LM performed maneuver, Δv components will be the v_G(LM) computed by the CSM program.
58	Pre-MCC1 (V37E 35E)	FL V50 N25*	P35	Request permission to perform MINKEY Rendezvous.	R1 00017 option code R2 Blank R3 Blank	Start P20 Upon crew's PRO, start MINKEY Rendezvous Sequence. Upon crew's ENTR, proceed with conventional sequence.	PRO to effect MINKEY Rendezvous.	DAP Data Load Routine (R03) should be performed before targeting program is called. Preferred-tracking-attitude yaw and pitch (R1 and R2 of NOUN 78) automatically set to zero and -35 deg respectively; rotation (R3) automatically set to zero or 180 deg, depending upon HDSUPFLG. Crew can change contents of NOUN 78 if he chooses. *NOTE.—FL V50 N25 display occurs only if MINKEY sequence initiated at this reset point.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
59		FL V50 N18**	P35	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to tracking attitude.	PRO	**Occurs only if $\Delta\theta > 10$ deg V06 N18 occurs only if crew keys PRO on FL V50 N18.
60		V06 N18**	P35	Nonflashing display of final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude and begin navigation. Should MGA reach 75 deg, terminate maneuver and enter ATT HOLD.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03), when last performed. When tracking attitude is obtained, crew can begin taking SXT marks at its discretion. Navigation continues automatically until crew requests final targeting computation. VHF marks, automatic.
61		FL V16 N45	P35	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display code indicating final cycle has not been requested (PRO).	R1 xxBxx Marks {VHF (first two) SXT (last two)} R2 xxBxx TFI {min (first two) sec (last two)} R3 -00001 preliminary cycle	Perform navigation; recycle for preliminary targeting solution upon the crew's VERB 32 ENTR. Cease navigation, compute and display final targeting solution upon crew's PRO.	Take SXT marks and monitor TFI; key VERB 32 ENTR for preliminary targeting solution; key PRO to terminate navigation and to perform final targeting computation.	Before crew keys PRO or V32E, TFI indicates time since TPI ignition. Crew keys PRO at TFI ≈ 12 min. Then, TFI indicates time from MCC1 ignition.

RECYCLE SEQUENCE (VERB 32 ENTR RESPONSE TO FL VERB 16 NOUN 45)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
61a		FL V06 N81	P35	Display preliminary computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)		Record PRO	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
61b		FL V16 N45	P35	Display number of VHF and SXT marks accumulated since last WRI; display TFI.	R1 xxBxx VHF, SXT marks R2 xxBxx min, sec TFI R3 -00001 preliminary cycle	Perform navigation; recycle steps 61a-61b upon the crew's keying VERB 32 ENTR. Cease navigation, compute and display final targeting solution (steps 62-63) upon the crew's keying PRO.	Take SXT marks and monitor TFI; key VERB 32 ENTR for preliminary solution (recycle); key PRO to terminate navigation and to perform final targeting solution.	Before crew keys PRO or V32E, TFI indicates time since TPI ignition. Crew keys PRO at TFI ≈ 12 min. Then, TFI indicates time from MCC1 ignition.

FINAL SOLUTION SEQUENCE (PRO RESPONSE TO FL VERB 16 NOUN 45)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
62		FL V06 N81	P35	Display final-computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)		Record PRO	
63		FL V16 N45	P35	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display MGA at t_{IG}.	R1 xxBxx VHF, SXT R2 xxBxx min, sec TFI R3 xxx.xx deg MGA	— — —	Record PRO	If v_G is ≥ 7 ft/sec, program proceeds to P40 sequence; if v_G is < 7 ft/sec, program proceeds to P41 sequence.

P40 SEQUENCE ($v_G \geq 7$ ft/sec)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
64a		FL V50 N18	P40	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude.	PRO	
64b		V06 N18	P40	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to flashing V50 N18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
64c		FL V50 N18	P40	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing V06 N18 display to return until trim maneuver has completed; then, FL V50 N18 returns. PRO again repeats the sequence; ENTR calls next step. The RHC can be used to establish wings level.
64d		FL V50 N25	P40	Request permission to perform gimbal drive test.	R1 00204 option code R2 Blank R3 Blank	Upon crew's PRO, perform gimbal drive test and then drive engine bell to trim position; upon crew's ENTR, inhibit drive test and drive engine bell to trim position.	PRO/ENTR Monitor gimbal drive test and gimbal drive to trim attitude.	
64e		V06 N40	P40	Display TFI, velocity to be gained (v_G), and sum of acquired velocity (Δv_M).	R1 xxBxx min, sec TFI R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform normal P40 procedures. At t_{IG} -35 sec, display blanks for 5 sec, then returns.	Monitor Perform usual P40 duties, e.g., ullage.	
64f		FL V99 N40	P40	Request burn permission.	R1, R2, R3 Same as step 64e	Upon crew's PRO, begin SPS burn at t_{IG}; follow normal P40 procedures. Upon crew's ENTR, bypass burn and go to step 64i.	At t_{IG} -5 sec, key PRO/ENTR, depending upon whether CSM is active or passive.	If PRO is not keyed until after t_{IG}, ignition occurs on the PRO.
64g		V06 N40	P40	Nonflashing display of TFC, v_G, and Δv_M.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform burn.	Monitor	Normal P40. R1 indicates TFI until ignition, then TFC.
64h		FL V16 N40	P40	Indicate completion of burn.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Upon crew's PRO, proceed to FL V16 N85.	PRO	Normal P40.
64i		FL V16 N85	P40	Display remaining velocity to be gained.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Normal P40. Upon crew's PRO, proceed to step 65.	Trim out residual Δv (if applicable) and key PRO.	

P41 SEQUENCE (v_G < 7 ft/sec)

64a		FL V50 N18	P41	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude. Upon crew's ENTR, bypass attitude maneuver and proceed to step 64d.	PRO/ENTR.	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
64b		V06 N18	P41	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to FL VERB 50 NOUN 18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.
64c		FL V50 N18	P41	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing VERB 06 NOUN 18 display to return until trim maneuver has completed; then, FL VERB 50 NOUN 18 returns. PRO again repeats the sequence, ENTR calls next step. The RHC can be used to establish wings level.
64d		V06 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Update v_G display every 1 sec.	Monitor	DSKY blanks at t_{IG} -35 sec.
64e		V16 N85	P41	Display (nonflashing) velocity to be gained (v_G) in CSM control coordinates. Indicate that AVERAGEG is being performed.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	At TFI = -30 sec, start AVERAGEG and flash ACTY every 2 sec.	Monitor	
64f		FL V16 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates and indicate time of ignition (t_{IG}) by flashing.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Continue updating every 2 sec. Upon crew's PRO, proceed to step 65.	If CSM active, use hand controller to null three components of v_G, then key PRO. If CSM passive, key PRO.	
65		FL V06 N33	P76	Display t_{IG}.	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Upon crew's PRO, proceed to FL V06 N84.	If displayed t_{IG} is correct, key PRO, if displayed t_{IG} is not correct, key V25E, load correct t_{IG}, and then key PRO.	The t_{IG} displayed is the t_{IG} used by the previous targeting program.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
66		FL V06 N84	P76	Display three components of Δv.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Upon crew's PRO, update LM state vector to reflect the added Δv.	If displayed Δv is correct, key PRO; if displayed Δv is not correct, key V25E, load correct values, and then key PRO.	If CSM performed maneuver, three components of Δv display will be zero; if LM performed maneuver, Δv components will be the v_G(LM) computed by the CSM program.
67	Pre-MCC2†	FL V50 N18**	P35	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to tracking attitude.	PRO	**Occurs only if $\Delta\theta > 10$ deg. V06 N18 occurs only if crew keys PRO on FL V50 N18. †NOTE.—No reset point. MINKEY Rendezvous cannot be initiated at this point.
68		V06 N18**	P35	Nonflashing display of final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude and begin navigation. Should MGA reach 75 deg, terminate maneuver and enter ATT HOLD.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03), when last performed. When tracking attitude is obtained, crew can begin taking SXT marks at its discretion. Navigation continues automatically until crew requests final targeting computation. VHF marks, automatic.
69		FL V16 N45	P35	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display code indicating final cycle has not been requested (PRO).	R1 xxBxx Marks {VHF (first two), SXT (last two)} R2 xxBxx TFI {min (first two), sec (last two)} R3 -00001 preliminary cycle	Perform navigation; recycle for preliminary targeting solution upon the crew's VERB 32 ENTR. Cease navigation, compute and display final targeting solution upon crew's PRO.	Take SXT marks and monitor TFI; key VERB 32 ENTR for preliminary targeting solution; key PRO to terminate navigation and to perform final targeting computation.	Before crew keys PRO or V32E, TFI indicates time since MCC1 ignition. Crew keys PRO at TFI ≈ 12 min. Then, TFI indicates time from MCC2 ignition.

RECYCLE SEQUENCE (VERB 32 ENTR RESPONSE TO FL VERB 16 NOUN 45)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
69a		FL V06 N81	P35	Display preliminary computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)		Record PRO	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
69b		FL V16 N45	P35	Display number of VHF and SXT marks accumulated since last WRI; display TFI.	R1 xxBxx VHF, SXT marks R2 xxBxx min, sec TFI R3 -00001 preliminary cycle	Perform navigation; recycle steps 69a-69b upon the crew's keying VERB 32 ENTR. Cease navigation, compute and display final targeting solution (steps 70-71) upon the crew's keying PRO.	Take SXT marks and monitor TFI; key VERB 32 ENTR for preliminary solution (recycle); key PRO to terminate navigation and to perform final targeting solution.	Before crew keys PRO or V32E, TFI indicates time since TPI ignition. Crew keys PRO at TFI 12 min. Then TFI indicates time from MCC1 ignition.
FINAL SOLUTION SEQUENCE (PRO RESPONSE TO FL VERB 16 NOUN 45)								
70		FL V06 N81	P35	Display final-computation Δv parameters.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)		Record PRO	
71		FL V16 N45	P35	Display number of VHF and SXT marks accumulated since last WRI; display TFI; display MGA at t_{IG}.	R1 xxBxx VHF, SXT R2 xxBxx min, sec TFI R3 xxx.xx deg MGA	---	Record PRO	If v_G is $\geq$ 7 ft/sec, program proceeds to P40 sequence; if v_G is < 7 ft/sec, program proceeds to P41 sequence.
P40 SEQUENCE ($v_G \geq$ 7 ft/sec)								
72a		FL V50 N18	P40	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude.	PRO	
72b		V06 N18	P40	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to flashing V50 N18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
72c		FL V50 N18	P40	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing V06 N18 display to return until trim maneuver has completed; then, FL V50 N18 returns. PRO again repeats the sequence; ENTR calls next step. The RHC can be used to establish wings level.
72d		FL V50 N25	P40	Request permission to perform gimbal drive test.	R1 00204 option code R2 Blank R3 Blank	Upon crew's PRO, perform gimbal drive test and then drive engine bell to trim position; upon crew's ENTR, inhibit drive test and drive engine bell to trim position.	PRO/ENTR Monitor gimbal drive test and gimbal drive to trim attitude.	
72e		V06 N40	P40	Display TFI, velocity to be gained (v_G), and sum of acquired velocity (Δv_M).	R1 xxBxx min, sec TFI R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform normal P40 procedures. At t_{IG} -35 sec, display blanks for 5 sec, then returns.	Monitor Perform usual P40 duties, e.g., ullage.	
72f		FL V99 N40	P40	Request burn permission.	R1, R2, R3 Same as step 72e	Upon crew's PRO, begin SPS burn at t_{IG}; follow normal P40 procedures. Upon crew's ENTR, bypass burn and go to step 72i.	At t_{IG} -5 sec, key PRO/ENTR, depending upon whether CSM is active or passive.	If PRO is not keyed until after t_{IG}, ignition occurs on the PRO.
72g		V06 N40	P40	Nonflashing display of TFC, v_G, and Δv_M.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Perform burn.	Monitor	Normal P40. R1 indicates TFI until ignition, then TFC.
72h		FL V16 N40	P40	Indicate completion of burn.	R1 xxBxx min, sec TFC R2 xxxx.x ft/sec v_G R3 xxxx.x ft/sec Δv_M	Upon crew's PRO, proceed to FL V16 N85.	PRO	Normal P40.
72i		FL V16 N85	P40	Display remaining velocity to be gained.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Normal P40. Upon crew's PRO, proceed to step 73.	Trim out residual Δv (if applicable) and key PRO.	

P41 SEQUENCE (v_G < 7 ft/sec)

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
72a		FL V50 N18	P41	Display required gimbal angles and request permission to perform automatic maneuver to burn attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to burn attitude. Upon crew's ENTR, bypass attitude maneuver and proceed to step 72d.	PRO/ENTR.	

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
72b		V06 N18	P41	Nonflashing display of final gimbal angles as automatic maneuver is performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to burn attitude.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, or terminates, use RHC to complete the maneuver manually. Observe that the nonflashing VERB 06 NOUN 18 returns to FL VERB 50 NOUN 18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03) when last performed. Any RHC input terminates automatic maneuver and returns to FL VERB 50 NOUN 18. A middle-gimbal angle of ±75 deg during an automatic maneuver causes the RCS DAP to terminate the maneuver, which must then be completed manually.
72c		FL V50 N18	P41	Request maneuver to trim attitude within RCS deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver. Upon crew's ENTR, proceed to next step.	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing VERB 06 NOUN 18 display to return until trim maneuver has completed; then, FL VERB 50 NOUN 18 returns. PRO again repeats the sequence, ENTR calls next step. The RHC can be used to establish wings level.
72d		V06 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Update v_G display every 1 sec.	Monitor	DSKY blanks at t_{IG} -35 sec.
72e		V16 N85	P41	Display (nonflashing) velocity to be gained (v_G) in CSM control coordinates. Indicate that AVERAGEG is being performed.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	At TFI = -30 sec, start AVERAGEG and flash ACTY every 2 sec.	Monitor	
72f		FL V16 N85	P41	Display velocity to be gained (v_G) in CSM control coordinates and indicate time of ignition (t_{IG}) by flashing.	R1 xxxx.x ft/sec v_G (x) R2 xxxx.x ft/sec v_G (y) R3 xxxx.x ft/sec v_G (z)	Continue updating every 2 sec. Upon crew's PRO, proceed to step 73.	If CSM active, use hand controller to null three components of v_G, then key PRO. If CSM passive, key PRO.	
73		FL V06 N33	P76	Display t_{IG}.	R1 ooxxx. hr (GET) R2 oooxx. min R3 oxx.xx sec	Upon crew's PRO, proceed to FL V06 N84.	If displayed t_{IG} is correct, key PRO; if displayed t_{IG} is not correct, key V25E, load correct t_{IG}, and then key PRO.	The t_{IG} displayed is the t_{IG} used by the previous targeting program.

TABLE 4.2.1-IV

MINKEY RENDEZVOUS DSKY PROCEDURES

No.	Entry Point	Display	PROG No.	Purpose	Register	CMC Operation	Crew Action	Remarks
74		FL V06 N84	P76	Display three components of Δv.	R1 xxxx.x ft/sec Δv_x (LV) R2 xxxx.x ft/sec Δv_y (LV) R3 xxxx.x ft/sec Δv_z (LV)	Upon crew's PRO, update LM state vector to reflect the added Δv.	If displayed Δv is correct, key PRO; if displayed Δv is not correct, key V25E, load correct values, and then key PRO.	If CSM performed maneuver, three components of Δv display will be zero; if LM performed maneuver, Δv components will be the v_G (LM) computed by the CSM program.
75	Pre-Final Phase*	FL V50 N18	P79	Display required gimbal angles and request permission to perform automatic maneuver to tracking attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform maneuver to tracking attitude.	PRO	*NOTE.—Not a true reset point, although program can be initiated by DSKY entry (VERB 37 ENTR 79 ENTR). Program initiates automatic maneuver to X-axis tracking attitude by loading zeros in Noun 78 (R2). Wings-level attitude is effected.
76		V06 N18	P79	Nonflashing display of final gimbal angles as automatic maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform automatic maneuver to tracking attitude. Should MGA reach 75 deg, terminate maneuver and enter ATT HOLD.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to complete the maneuver manually.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03), when last performed.
77		FL V16 N54	P79	Display range, range rate, and theta.	R1 xxx.xx n.mi. range R2 xxxx.x ft/sec range rate R3 xxx.xx deg theta	Execute Verb 83, Rendezvous Parameter Display Routine (R31). Update display every 2 sec.	Monitor PRO when ready.	
78		FL V37	P79	Indicate MINKEY termination.	- - -	- - -	Select P00 or P47 as desired.	End of MINKEY Rendezvous.

**AZIMFLAG will be in the set configuration (for a wings-level attitude) if MINKEY sequence has been initiated (by PRO to FL VERB 50 NOUN 25, R1 = 00017) and P20 has not been later, "permanently," terminated. (See P20 Assumptions — Rendezvous Flag — in GSOP Section 4.) AZIMFLAG is not affected by temporary interruption of MINKEY.

BLANK

4.2.2 P21, Ground-track Determination—CMC

P21 has two distinct uses. First, as P21 ground track determination, it can be used to predict marktaking opportunities for P22 orbital navigation. The astronaut specifies a time (GET) and vehicle (CSM or LM). The program integrates the appropriate vehicle state vector to that time, converts it into latitude, longitude and altitude, and displays the result. Second, with the latitude-longitude information returned by P21 and charts of the lunar terrain, landmarks can be identified in advance for marktaking. The altitude effectively determines the duration of the marktaking window.

An optional trajectory parameter display can also be obtained in P21 by using NOUN 73, which is useful during P23 cislunar coast and, in certain conditions in the vicinity of the moon, to determine the re-entry flight-path angle (γ) at t_{IG} when using P37. (See paragraph 5.2.6.8.) NOUN 73 displays the altitude (range), velocity, and flight-path angle of the trajectory that results from extrapolating the current state vector of the CSM to some future time; e.g., LOI during the translunar phase and reentry time during the return.

Table 4.2.2-I lists the displays that occur in P21 with descriptions of the associated program features. Figure 4.2.2-1 is the program flowchart.

4.2.2.1 Options

The latitude, longitude and altitude predictions of future vehicle positions produced by the advanced ground tracking option in P21 can be used (1) to select relevant portions of the lunar landscape on maps preliminary to making out-the-window landmark identification, and (2) to designate unknown landmark coordinates in P22 for auto optics acquisition. In lunar orbit, sufficient uncertainty is introduced into the vehicle state vectors by the current onboard potential model during extrapolation that coordinate predictions may contain errors of 1 or 2 n. mi. This presents no problem for option 1, but requires that probable state vector errors be taken into account for option 2. Variations in lunar gravity have a negligible effect at cislunar distances, so that the NOUN 73 option is accurate enough.

4.2.2.1.1 Advanced Ground-track Determination.—In near-earth or near-moon orbit, the astronaut can specify a future time to the program and have his coordinates (latitude, longitude, altitude) for that time returned. An optional recycle on the final latitude-longitude-altitude display will cause the program to return to the second display where the desired time was input (VERB 06 NOUN 34) and return the time

TABLE 4. 2. 2-I

P21 (CSM) GROUND-TRACK DETERMINATION PROCEDURES

DSKY	Register	Comments
Key V37 E21E	DSKY P21	Only requirement for P21 is a valid state vector. ISS not required.
FL V04 N06	R1 00002 R2 00001 R3 Blank	Vehicle code in R1=00002 R2=00001 indicates this vehicle; R2=00002 indicates other vehicle: Key PRO if correct; keying V22E will blank R2, permitting vehicle code to be changed.
FL V06 N34	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec	Request load desired GET (T LAT LONG) in hours, minutes, and seconds to nearest 0. 01 sec. For present time set R1, R2 and R3 to all zeros. PRO to compute latitude, longitude, altitude for specified GET; V25E to change time.
FL V06 N43	R1 xxx. xx deg R2 xxx. xx deg R3 xxxx. x n. mi.	Program displays vehicle latitude and longitude in degrees to nearest 0. 01 deg in R1 and R2 (+is North or East, respectively) for specified GET. R3 contains altitude in nautical miles to nearest 0. 1 n. mi. measured from launch pad radius (earth) or latest landing site radius (moon). V32E will increment GET (T LAT LONG) initially specified by 10 minutes; recycle to V06N34 display. T LAT LONG may then be overwritten via V25E to any desired time. Keying PRO or V34E will terminate P21.
V06 N73E FL V37	R1 xxxxxB n. mi. R2 xxxxx. fps R3 xxx. xx deg	Altitude to nearest 10 n. mi. Inertial velocity to nearest 1 fps. Flight path angle to nearest 0. 01 deg. This display may be obtained in P21 any time after integration is complete.

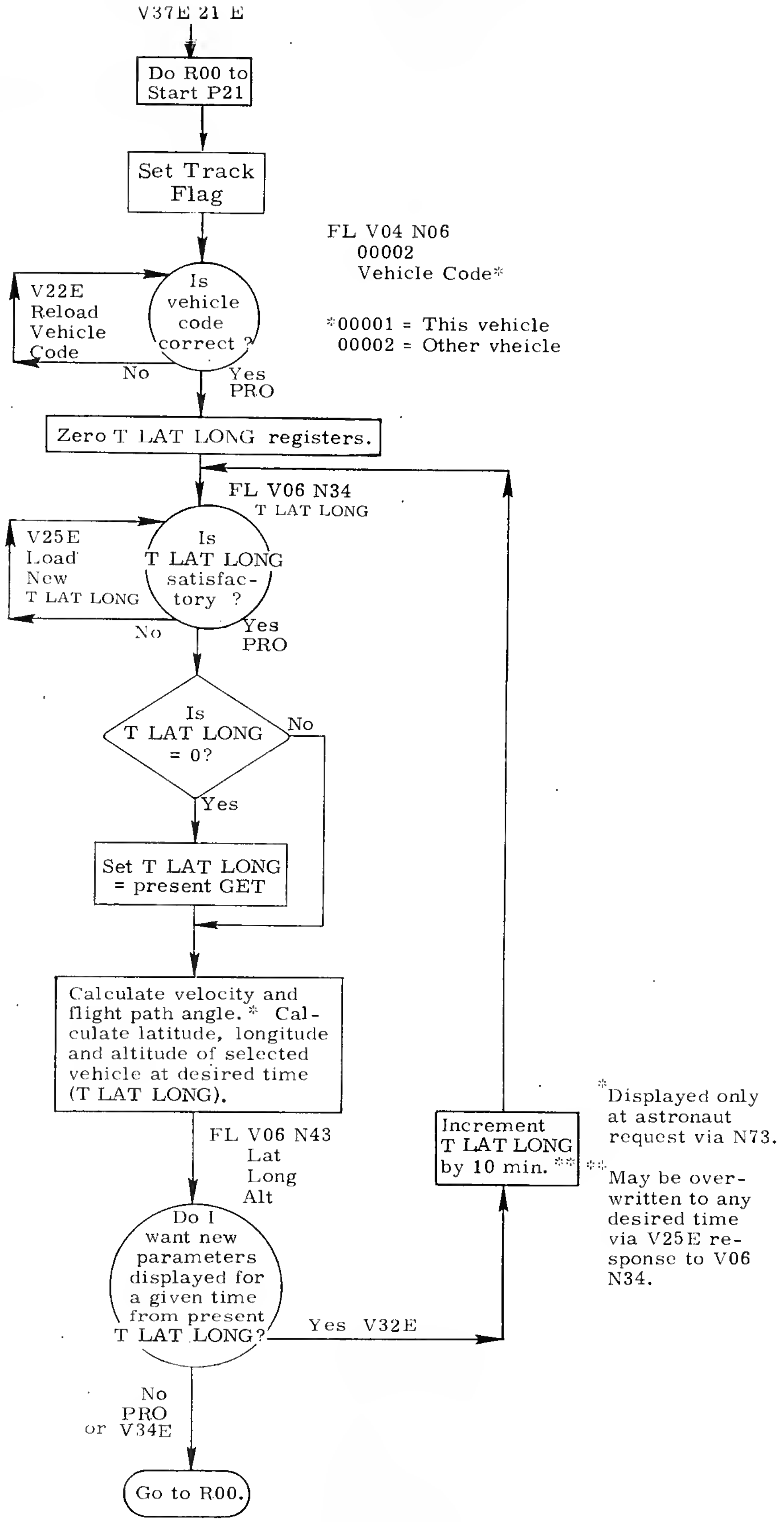

Figure 4.2.2-1. Ground-track Determination Program (CSM P21)

originally specified incremented by ten minutes. The astronaut can then PRO to obtain the T LAT LONG corresponding to the original GET plus ten minutes, or reject it by keying VERB 25 ENTR and overwrite any desired T LAT LONG. In this way he can identify particular landmarks available for P22 in advance and anticipate promising marktaking opportunities.

4.2.2.1.2 Orbital Parameter.—The P21 NOUN 73 option is primarily used after a P23 navigation sequence to determine whether the trajectory produced by the spacecraft's newly-updated state vector results in satisfactory terminal conditions at the target planet. Alternatively, the VERB 82 orbital parameters display (see R30, paragraph 9.2.3) can be called after the latitude-longitude-altitude display; i.e., after state-vector integration is complete. VERB 82 displays apogee and perigee height and time of free fall; this trajectory information supplements NOUN 73 and P37. (NOUN 73 is also used—in rare situations—to determine the value of the re-entry angle for P37. See paragraph 5.2.6.8.)

4.2.2.2 Limitations

To predict the future orbital position of a vehicle (LM or CSM), P21 must obtain a precision integration of its state vector over the specified time interval. The further in advance the request is made (i.e., the larger the extrapolation interval), the less precise is the coordinate information returned. In earth or lunar orbit, the quality of the precision integration—and therefore the predictions—is determined primarily by the quality of the potential model used in the integration routine for the earth or moon gravitation.

On the first pass through P21, the program uses precision integration to compute the desired vehicle state vector at the specified T LAT LONG. Subsequent computations via the VERB 32 ENTR option use the previous state vector to start the next iteration without, however, ensuring that subsequent integrations are precision. Use of the VERB 32 ENTR option depends on the closeness of the desired times. If the times are reasonably close, the option should be used. If not, it is quicker to reselect P21.

4.2.3 P22, Orbital Navigation—CMC

Table 4.2.3-I lists the purposes P22 was designed to achieve.

TABLE 4.2.3-I

PURPOSES OF CSM P22 ORBITAL NAVIGATION

1.	Locate and track a landmark suitable for navigation
2.	Obtain sighting marks on the chosen landmark
3.	Calculate the orbital parameter changes generated by the landmark sighting marks
4.	Display the orbital parameter changes generated by the first sighting mark on a landmark, for decision by the navigator/ground on the validity of the landmark and navigation process prior to incorporation of state vector changes resulting from the sighting marks
5.	Provide updated coordinates of the known landmarks
6.	Provide coordinates of unknown landmarks
7.	Track a preloaded landing site
8.	Provide coordinates of a new landing site (treated as an unknown landmark)
9.	Provide coordinates of an offset landing site
10.	Point the optics along an advanced orbit ground track for tracking and mapping a new landing site.

The onboard navigation and landmark mapping capabilities of P22 are not yet being used in the way originally intended, as optical marks are not processed onboard.* Items 2 and 7 are the only applications authorized. Optical marks are taken on the landing site and nearby known landmarks using state vector values and landmark coordinates supplied by the ground. A zero W-matrix is used and marks taken are not incorporated onboard but are downlinked for use in ground computations. Primary ground track data, together with downlinked optics marks are used to compute the spacecraft's state vector and acquisition orientation for the next marktaking sequence; these computations are uplinked shortly before they are required.

The program flowchart, Figure 4.2.3-1, delineates the decision points in P22; however, many of the optional paths are not significant at present.

* This statement applies to the G and H missions and will probably remain valid until an adequate lunar potential model is obtained.

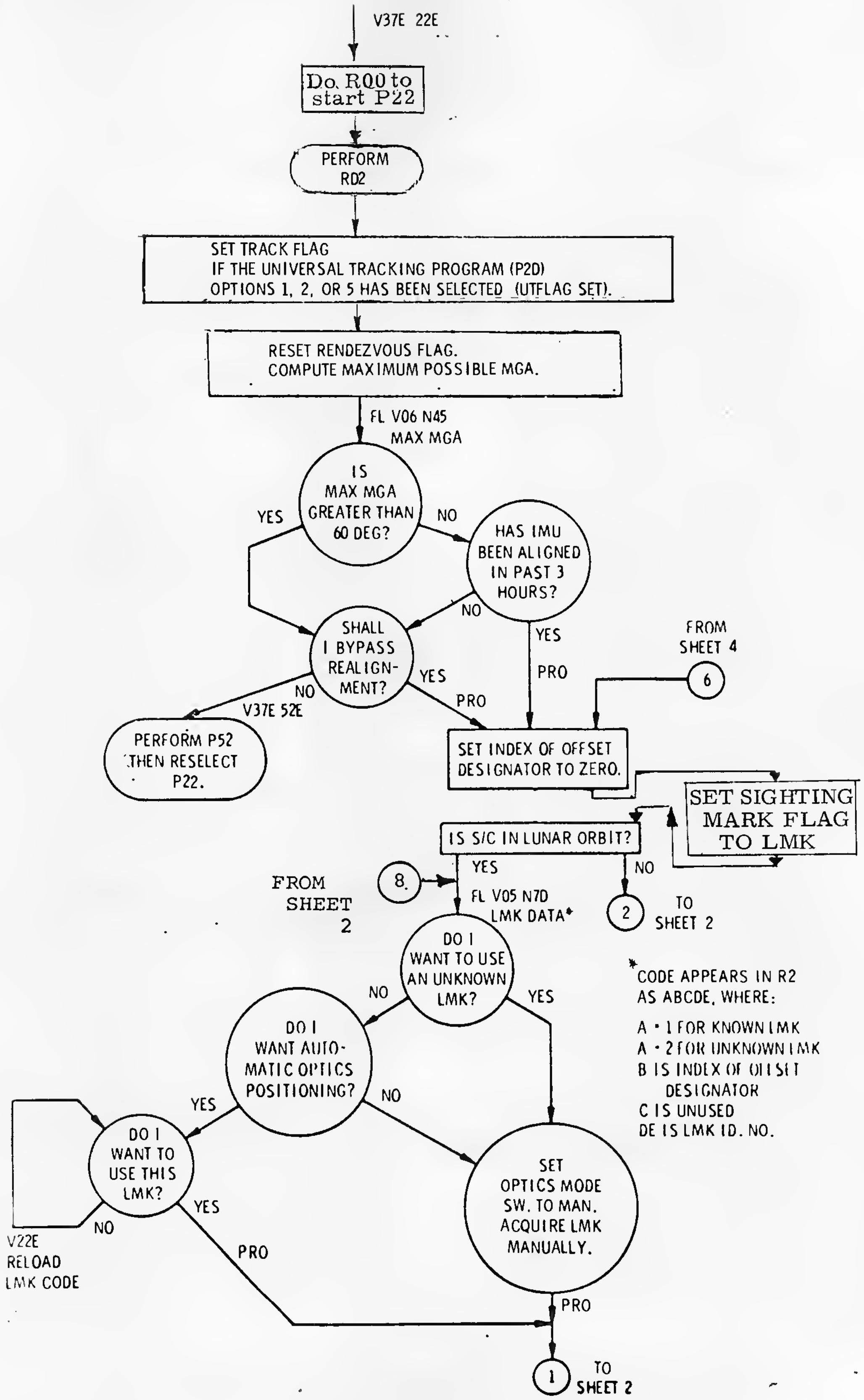

Figure 4.2.3-1. Orbital Navigation Program (CSM P22)
(Sheet 1 of 4)

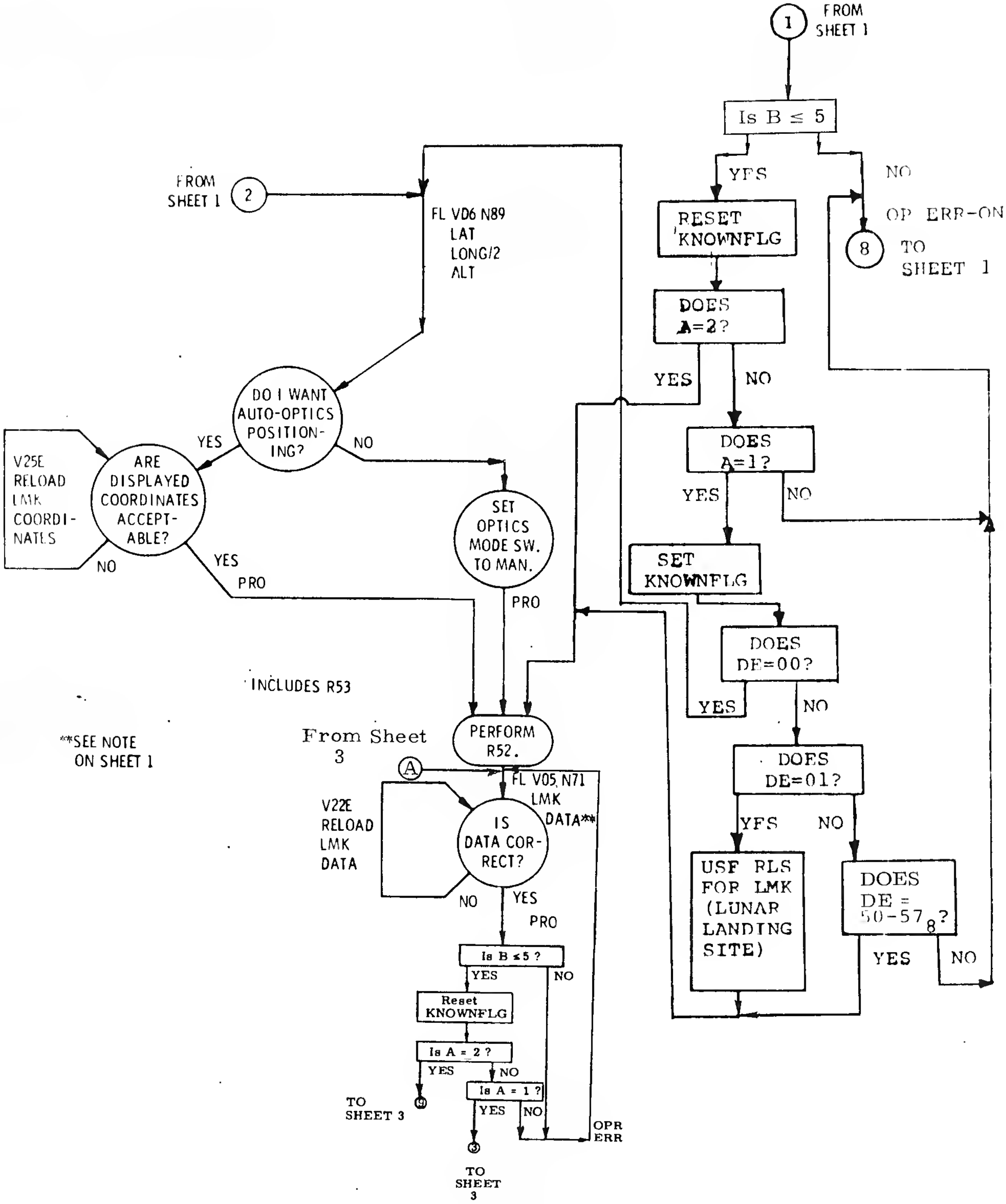

Figure 4.2.3 -1. Orbital Navigation Program (CSM P22)
(Sheet 2 of 4)

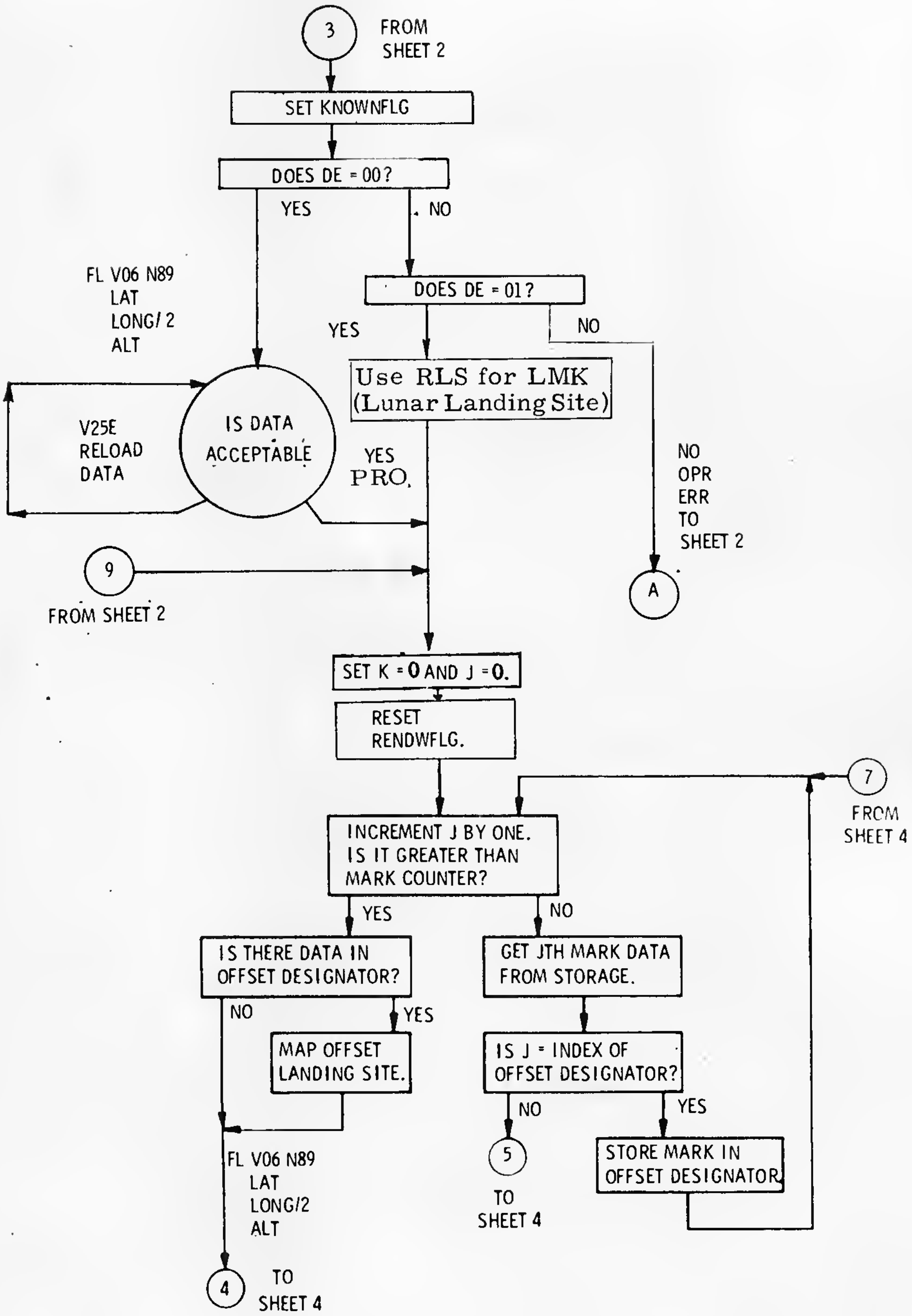

Figure 4.2.3 -1. Orbital Navigation Program (CSM P22) (Sheet 3 of 4)

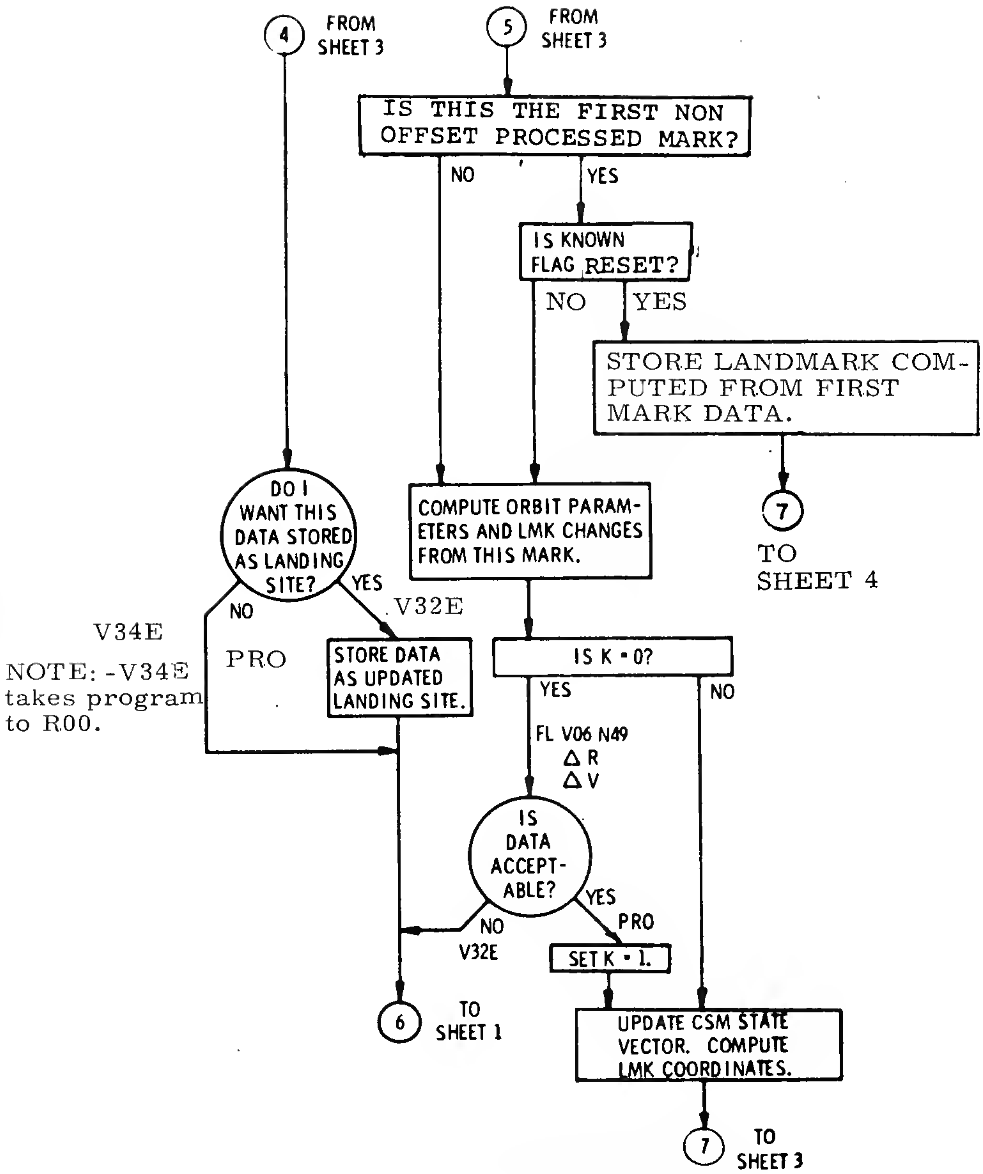

Figure 4.2.3-1. Orbital Navigation Program (CSM P22) (Sheet 4 of 4)

Procedures that ensure proper landmark acquisition and marktaking are a precondition to successful landmark navigation using P22, whether marks are processed onboard or not. Because of the restricted use currently made of P22, the procedures in Table 4.2.3-II and the accompanying discussion are concerned mainly with correct landmark acquisition and marktaking technique and not with evaluation of onboard updates, navigation, or mapping.

4.2.3.1 Program Options

The only live option in P22 at present is the choice between designating a known landmark which has its coordinates stored in the CMC (R2 equals 10001 for the landing site), or an unstored known landmark (R2 equals 10000), whose latitude, longitude, and altitude must be input by the astronaut. The latter option affords some flexibility in pointing the optics if there is any uncertainty in the landmark's true location. The IMU must be up and recently aligned since optics CDU angles recorded for each mark are referred to platform CDU angles. The quality of navigation data, therefore, depends directly on IMU alignment.

The program options that permit marks to be processed onboard, unknown landmarks to be mapped, and offset landing sites to be designated are not used.

4.2.3.2 Landmark Tracking Geometry

Figure 4.2.3-2 shows the geometry for tracking a landmark in a 60-n. mi. circular lunar orbit. Recommended marktaking technique requires that five marks be taken equally spaced over the plus-55- to minus-55-deg marktaking window. The advantage of oblique lines-of-sight on the first and last marks diminishes rapidly beyond ± 45 deg. Consequently, marks taken symmetrically and at equally spaced intervals are preferable to marks taken asymmetrically at the extremes of the marktaking window. The interval between marks for the 76-deg (100-second) minimum marktaking window is 19 deg (25 seconds); for the 110-deg (180-second) maximum window, the interval between marks is 27.5 deg (45 seconds).*

4.2.3.2.1 <u>Landmark Tracking Modes.</u>—Two landmark tracking modes have been defined which, with variations and in combination, suffice to define all practicable

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*Illustrations and numerical data, MSC Internal Note No. 69-FM-81, "Lunar Landmark Tracking Attitude Studies," C. R. Hunt, TRW Systems, April 11, 1969.

TABLE 4.2.3-II

P22 (CSM) DSKY PROCEDURES (SHEET 1 OF 3)

Step	DSKY Activity	Registers	Comments
1.	Key V37E 20E		See paragraph 4.2.1 for description of P20.
2.	FL V04 N06	R1 00024 Checklist code R2 oooox Option code	1. Load R2 with 00002. PRO.
3.	FL V06 N78	R1 ±xxx.xx deg (γ) R2 ±xxx.xx deg (ρ) R3 ±xxx.xx deg (o)* *Omicron (o) is not relevant to this option.	1. Load R1 and R2 with angles. PRO.
4.	FL V06 N79	R1 ±x.xxxx deg/sec rate R2 +xxx.xx deg deadband R3 Blank	1. Load desired rotation rate and deadband. PRO. 2. Note that R2 is preloaded with last R03 deadband. When R2 contains zero, minimum deadband (0.5 deg) is used.
5.	FL V06 N34	R1 +ooxxx hr (GET) R2 +oooxx min R3 +oxx.xx sec	1. Load desired time of maneuver (pad). PRO. 2. Note that if time loaded is in the past, rotation begins immediately. Otherwise, rotation about the vector specified in NOUN 78 begins at the time specified in NOUN 34.
6.	Key V37 E22E		P22 entered 5 to 10 minutes prior to point of closest approach. Note: Before entering P22, the SC will have been maneuvered to the acquisition attitude via VERB 49E. Optics may be driven to acquisition shaft and trunnion angles by keying VERB 41 NOUN 91E loading R1 and R2 with 000.00°/45.000°.

TABLE 4.2.3-II

P22 (CSM) DSKY PROCEDURES (SHEET 2 OF 3)

Step	DSKY Activity	Registers	Comments
7.	FL V06 N45	R1 Blank R2 Blank R3 oxx.xx deg	Maximum possible MGA (angle between Y_{SM} and $\underline{V} \times \underline{R}$) is displayed. If angle is acceptable, PRO.
8.	FL V05 N70	R1 Blank R2 ABCDE R3 Blank	Key VERB 22E to select R52 auto optics option, load R2 with 10000 or 10001 and ENTR. A 1 signifies known landmark A 2 signifies unknown landmark B index of offset designator C not used DE landmark ID number PRO when correct values loaded. If optics were not driven to 0 degrees shaft and ~ 45 degrees trunnion before (See step 1), they can be positioned manually as follows: OPTICS ZERO - OFF OPTICS MODE - MANUAL Drive optics to 45 degrees with OHC and return OPTICS MODE switch to CMC
9.	FL V06 N89	 R1 xx.xxx deg R2 xx.xxx deg R3 xxx.xx n.mi.	Only appears if R2 = 10000, (step 8) or in earth orbit. Latitude; + is North. Longitude divided by 2; + is East. Altitude above Fischer Ellipsoid or mean lunar radius.
10.	V06 N92	R1 xxx.xx R2 xx.xxx R3 Blank	Shaft angle Trunnion angle R52 will drive optics angles to point at landmark. (Although unlikely, 00404 alarm will flash if T angle exceeds 90°). The alarm can be reset when the trunnion comes within 90°. The optics will track automatically when the trunnion angle is below 49.7754°. The VERB 06 NOUN 92 display will not appear unless the OPTICS ZERO switch is OFF and the OPTICS MODE switch is in the CMC position.

TABLE 4.2.3-II

P22 (CSM) DSKY PROCEDURES (SHEET 3 OF 3)

Step	DSKY Activity	Registers	Comments
11.	FL V51		R53 Sighting Marks Routine is selected by switch to MAN and VERB 51 Please Mark request will flash until 5 marks are taken. Mark Reject button will erase last mark data and decrement mark counter. To designate a sighting mark on an offset landing site, key in VERB 52 ENTR after the mark is made. The index of offset designator will be set to the value of the mark counter and displayed in NOUN 71 (R2) following termination of the Sighting Mark Routine.
12.	FL V50 N25	R1 00016 R2 Blank R3 Blank	Terminate mark sequence flashes after fifth mark. PRO will return to P22.
13.	FL V05 N71	R1 Blank R2 ABCDE R3 Blank	Same as V05 N70 measurement ID, confirm and PRO.
14.	FL V06 N49	R1 xxx.xx n.mi. R2 xxxx.x fps R3 Blank	DELTA R DELTA V Hold for 11 seconds and PRO (W-matrix is zero so both DELTA R and DELTA V will be zero).
15.	FL V06 N89	R1 xx.xxx deg R2 xx.xxx deg R3 xxx.xx n.mi.	Same as step 9, confirm and V34E Latitude; + is North. Longitude divided by 2; + is East. Altitude above Fischer Ellipsoid or mean lunar radius.
16.	FL V37		Return to CMC auto. V34E keyed above terminates P22 and causes V37 to flash after processing delay.
17.	00E		00E response to FLV37 transfers to R00

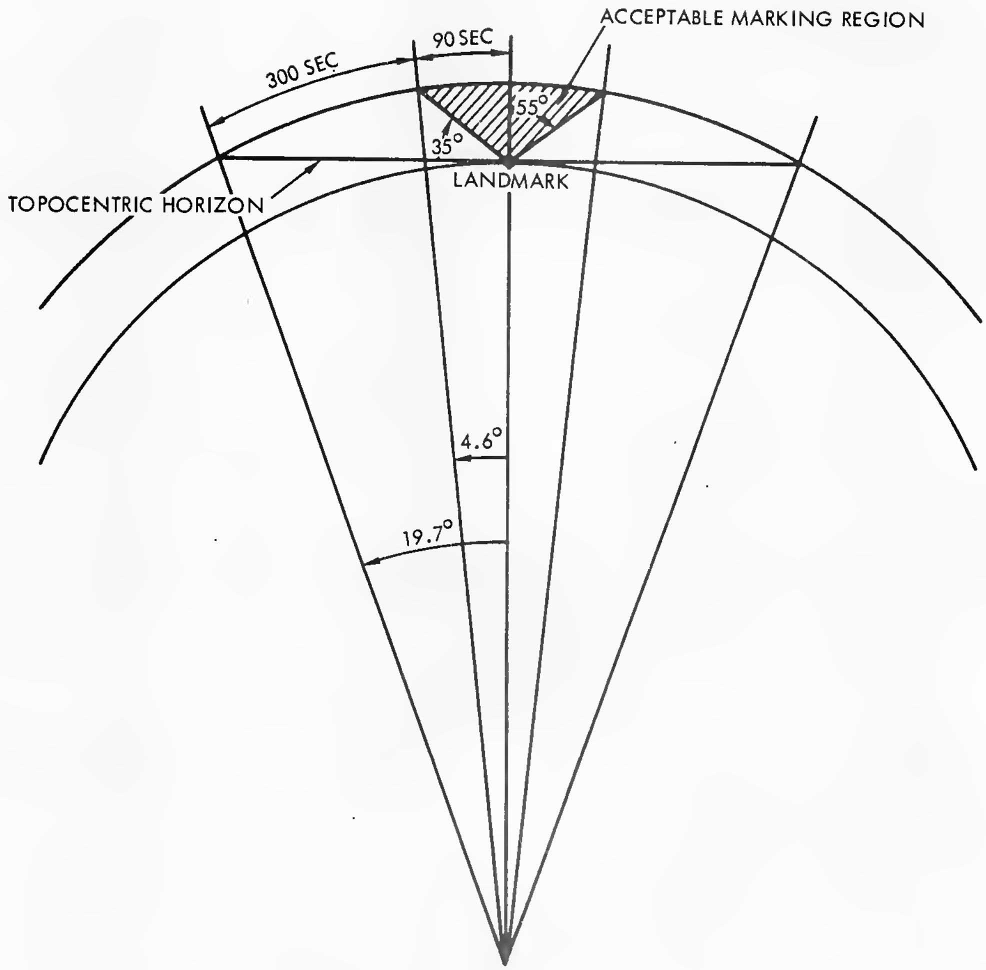

Figure 4.2.3 -2. Landmark Tracking Geometry for a 60-Nautical Mile Circular Lunar Orbit (CSM P22)

landmark tracking possibilities.* Mode I is used for landmark tracking in the CSM/LM docked configuration when the LM blocks portions of the CSM SCT and SXT FOV. (See Figure 4.2.3-3.) An area of diminished brightness, similar to the one shown for the SCT, also exists for the SXT. The lunar landscape is sufficiently bright, however, that the total FOV of both instruments is assumed to be useful for landmark tracking. Mode I requires that the CSM/LM combination be maneuvered —well before marks are taken—to an inertial attitude that becomes -2 deg nosedown with respect to the local horizontal at the 55-deg start of the marktaking window. This position affords a good angle of forward vision for acquisition.

Figure 4.2.3-4 illustrates the geometry for Mode I landmark tracking. The landmark enters the SCT FOV 148 seconds before the closest point of approach (CPA) to the landmark at an elevation angle of 21 deg; it enters the SXT FOV 112 seconds before the CPA at an elevation angle of 28.2 deg. At 90 seconds before CPA and at a 35-deg elevation angle, the spacecraft X-axis reaches the predetermined -2.1-deg attitude with respect to the local horizontal, and a -0.3 deg/sec pitch rate is started.** This causes the vehicle and the optics shaft axis to rotate through -54 deg while traversing the 180-second (110-deg) marktaking window.

The -2.1-deg attitude allows 58 seconds and 22 seconds for acquisition in the SCT and SXT, respectively, before the pitchdown rate is initiated. The landmark will remain in the SXT FOV throughout the acceptable marking region, even if the pitch rate is slightly less than 0.3 deg/sec or if its initiation is slightly delayed.

A variant of Mode I calls for an 8-deg nosedown attitude at the 90-sec/35 deg pitch down point, plus a -0.2 deg/sec rate. With this version, the landmark enters the SCT FOV 38 seconds before the pitch is initiated, and enters and leaves the SXT FOV at almost exactly the 55-deg boundaries of the marktaking window, leaving almost no margin for error.

Mode III is used after separation when the LM no longer blocks the CSM optical FOV. This mode consists of a -22-deg nosedown local attitude hold, accomplished by maneuvering the spacecraft X-axis 22 deg below the local vertical and immediately initiating a 0.05 deg/sec negative (orbrate) pitch rate, which effectively maintains

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*Actually four modes were defined in the Hunt Study but Mode II is a combination of Modes I and III and Mode IV is a roll mode not currently practiced for P22.

** This same inertial attitude is equivalent to +2.5 degrees at the landmark local vertical.

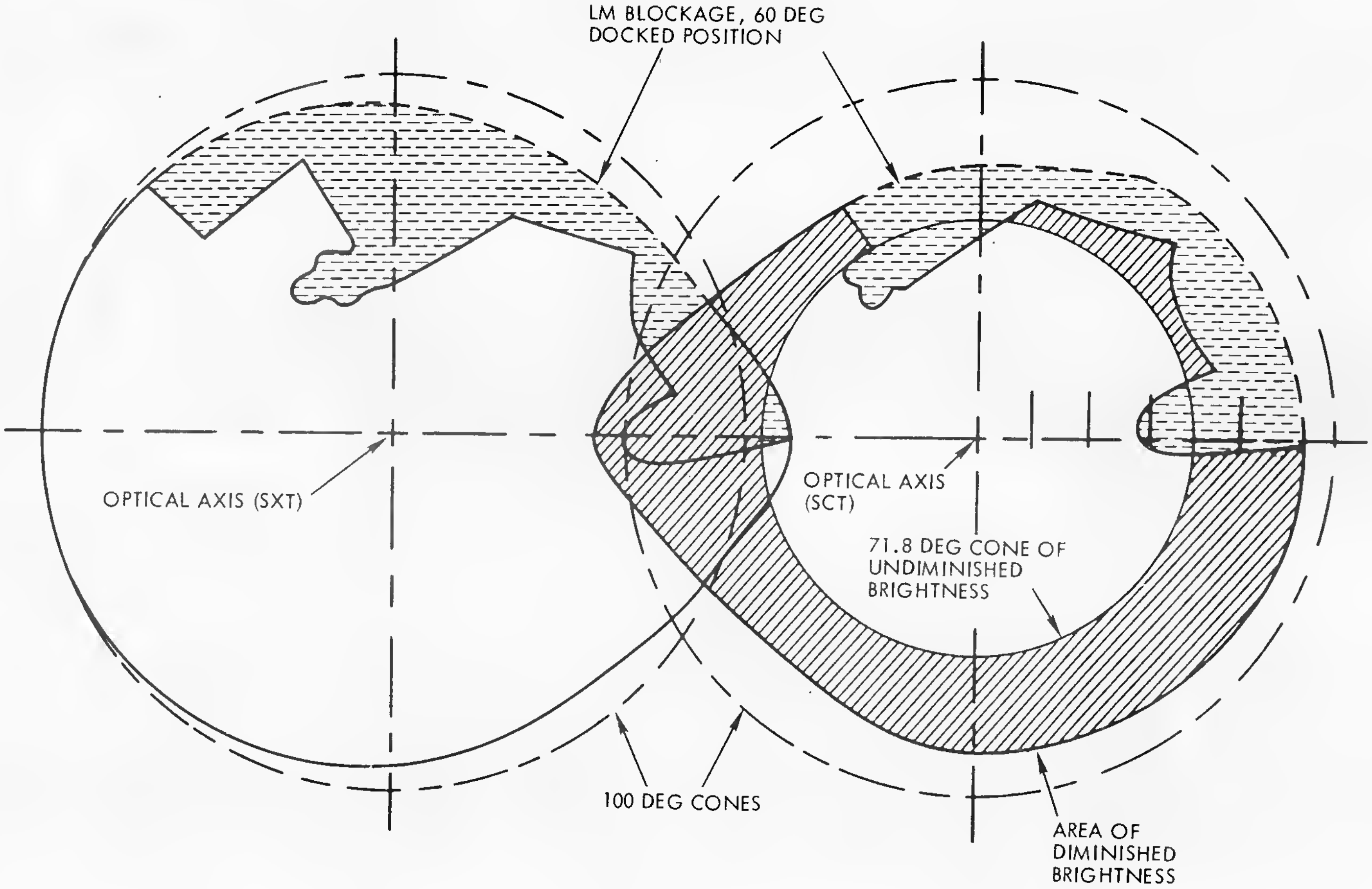

Figure 4.2.3 -3. SXT and SCT Fields of Coverage

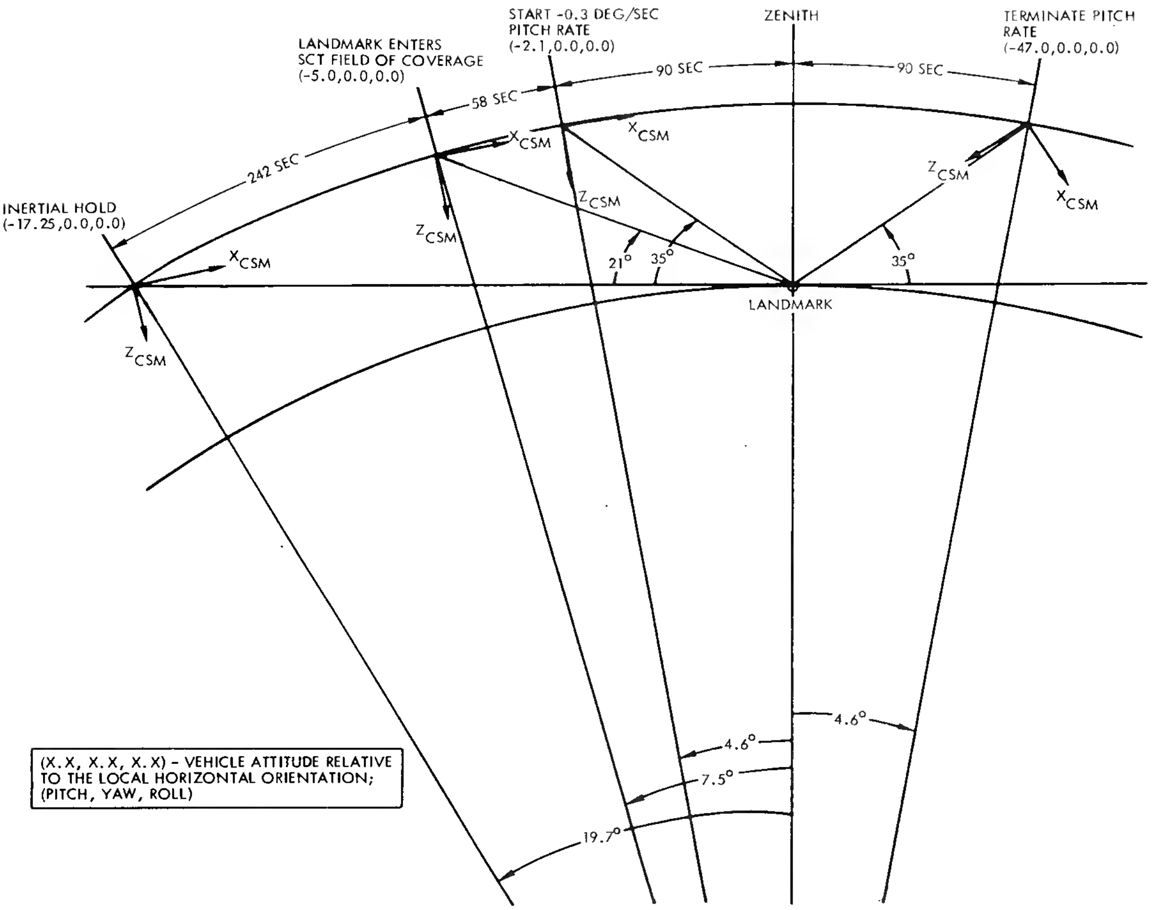

Figure 4.2.3 -4. Tracking Geometry for Mode I Landmark Tracking (CSM P22)

the spacecraft attitude constant at 22 deg below the local horizontal. Figure 4.2.3-5 shows the elevation angles and times a landmark will enter the SXT and SCT FOV and exit the SXT. In Mode III, 5 or 10 deg of the marktaking window after CPA is traded for 30 to 60 seconds of acquisition time, i.e., pre-mark tracking of the landmark. Mode III orbrate tracking is the standard undocked landmark tracking method because it requires the minimum feasible pitchdown rate and, therefore, minimizes RCS fuel use. The important variable in Mode III is the choice of an optimum amount of nosedown attitude.

In the G-mission, visual acquisition and identification of landmarks through the spacecraft windows proved relatively easy. It is still a problem, however, to find landmarks using the SXT—with its narrow field of view—when auto optics pointing information contains significant errors. An appreciable noseup acquisition attitude seems necessary if time is required to scan large areas using the SXT with its 1.8-deg FOV. In situations where the target is a terrain feature and not the LM, optical acquisition in the SCT would appear to be a good possibility. If feasible, acquisition via the SCT might allow a few deg more negative acquisition attitude, so that 30 seconds of acquisition time could be exchanged for a full post-zenith marktaking window.

4.2.3.2.2 Optical Tracking Rate Limitations.—Implicit in the foregoing discussion of acquisition attitudes and tracking rates is the assumption that both the spacecraft X–Z plane and the landmark are in the orbital plane. This is not so. If the landmark is in the orbital plane, the spacecraft must be rolled out of the orbital plane to prevent excessive shaft rates that would result if the LOS to the landmark were permitted to pass within a few deg of the shaft.

At the closest point of approach, the trunnion rate goes to zero for an instant and the shaft must rotate at the actual LOS rate times the cosecant (1/sine) of the roll angle. If the roll angle is small, the cosecant may be very large and the maximum shaft rate correspondingly high, e.g., the shaft rate approaches infinity as the off-axis angle approaches zero. A 10-deg roll angle gives about six times the approximately 5/6-deg/sec LOS rate. At 60 n. mi., this produces a shaft rate of 5 deg/sec, well within the ±15 deg/sec shaft drive rate limit.

The 10-deg roll is positive (right) since this rotates the optics FOV into the less obstructed quadrant of the CSM FOV occulted by the LM before separation. (See Figure 4.2.3-3.) If the landmark is off the ground track appreciably (particularly between 4 deg and 16 deg to the left at the groundtrack), the roll angle must be modified accordingly.

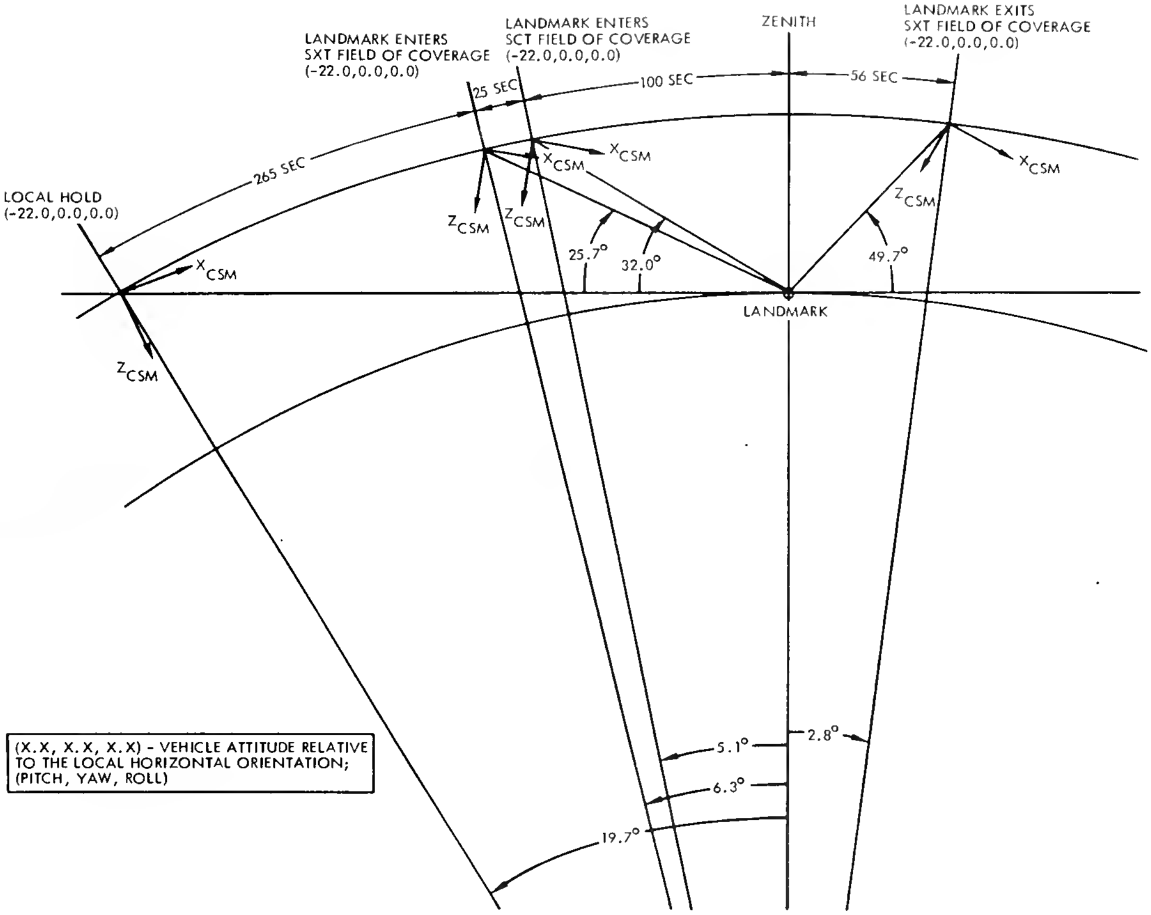

Figure 4.2.3 -5. Tracking Geometry for Mode III Undocked Landmark Tracking (CSM P22)

4.2.3.3 Acquisition Attitudes and Marktaking Pitch Rates

The principal decisions that must be made in P22, as it is currently used, are the selection of the extended verbs and routines required to obtain the desired attitude and pitch rate—with particular emphasis on the timing and magnitude of rates and maneuvers. The two fundamental tracking modes, with several variations, involve various combinations of vehicle attitude and pitch rate, depending on whether marks are to be taken in the docked or undocked configuration and on the size of the acquisition and marktaking windows required.

Maneuvers to inertial acquisition and tracking attitudes can be performed using the Crew Defined Maneuver Routine, R62, obtained by keying VERB 49. Attitude rates can be obtained by a number of alternative methods. Orbrate (-0.05 deg/sec) can be attained by loading a minimum rate into the DAP and commanding a maneuver to an attitude sufficiently far (e.g., 45 deg) from the initial attitude that it will not be reached during the marktaking interval, so that the vehicle will continue to pitch at orbrate while the landmark is acquired and marks are taken.

After the landmark has been acquired, the Minimum Impulse Controller can be used, in the CMC FREE position, to impose a pitch rate prior to marktaking. Option 2 of the Universal Tracking and Rendezvous Navigation Program (P20, paragraph 4.2.1) is also available for initiating a constant-rate pitch maneuver that will keep the landmark within the SXT FOV.

4.2.3.4 Preliminary Procedures

The IMU is aligned via P52 as near to the time landmark tracking begins as is convenient—usually about 1 hour before P22 is entered. The landing site alignment used is that in which the stable member X-axis is aligned to the landing site local vertical. To obtain the 22-deg nosedown, 10-deg left roll acquisition attitude defined above, key VERB 49E and load R1, R2 and R3 in the NOUN 22 display with 10 deg, 248 deg and 0 deg, respectively (248 deg represents a 112-deg pitch down from the landmark local vertical).

In the H1-mission, the attitude required for acquisition was computed and the P22 PAD voiced up immediately before the VERB 49 maneuver to the acquisition attitude. In the G-mission the maneuver PAD was transmitted 45 minutes to an hour ahead because the landing site was farther east and there was insufficient time for tracking and computation of new PAD values before the maneuver. For westerly landing sites, the CSM can be tracked through the period after communication is reestablished,

less than an hour before the maneuver. In this way state-vector information with the smallest possible extrapolation and potential modeling errors can be incorporated into the computed VERB 49 roll, pitch and yaw values.

The VERB 49 manuever to the inertial hold attitude that produces the -2.1-degree attitude specified at the -90-second pitchdown point (Figure 4.2.3-4), can be performed 10 minutes or more in advance.* This allows time to enter P20 early, set up option 2 to initiate pitchover at the appropriate time, and then call P22. (See Table 4.2.3-II.) At the time specified in P20, the pitch maneuver is initiated automatically. Meanwhile, auto optics is tracking the landmark, and the astronaut is monitoring with the SXT. At an elevation angle of +55 deg, and with a -0.3 deg/sec pitch rate, the vehicle angular rate very nearly matches the LOS rate (0.34 deg/sec). Switching to manual optics control at this time is, therefore, desirable since minimal OHC maneuvers are required of the astronaut.

4.2.3.5 Alarms

When the PROG alarm light on the DSKY is illuminated, either VERB 05 NOUN 09 will be displayed automatically with R1, R2, or R3 containing the alarm code, or the crew can have the code displayed by keying VERB 05 NOUN 09 into the DSKY. The crew can then identify and correct the alarm condition and key RSET to continue. A list of alarms that may be encountered in P22 and an explanation of each follows:

a. Alarm 00110 indicates that the MARK REJECT pushbutton has been depressed when no mark to reject. Key RSET to extinguish PROG light. Continue normal operation.

b. Alarm 00115 indicates that V41N91 was keyed when the OPT MODE switch was not in the CMC setting. (The OPR ERR light also illuminates for this alarm.) Set the OPT MODE switch to CMC, and the OPT ZERO switch to OFF.

c. Alarm 00116 indicates that the OPT ZERO switch was taken out of the ZERO setting before the 15-sec–zero-time elapsed. Set OPT ZERO switch to ZERO setting for 15 sec.

d. Alarm 00120 indicates that optics torque has been requested, but that optics have not been zeroed since last freshstart or restart. Set the OPT ZERO switch to OFF, then to ZERO for approximately 15 sec.

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* The convention in the illustrations (pitch, roll, yaw) is not consistent with the roll, pitch, yaw convention used in loading R1, R2 and R3 in VERB 49, and also omits the 10-degree roll, and the use of inertial landmark local vertical coordinates.

e. Alarm 00121 indicates that spacecraft attitude rates are too great, resulting in an automatic rejection of the mark. Repeat mark.

f. Alarm 00210 indicates that the inertial subsystem (ISS) is not on. Re-do the ISS turn-on procedures. If alarm recurs, perform freshstart via VERB 36. Consult MSFN.

g. Alarm 00220 indicates that the IMU orientation is unknown. Align the IMU. If aligned, set REFSMMAT flag.

h. Alarm 00404 indicates that a trunnion angle greater than 90 deg is required to acquire the star or landmark. Maneuver spacecraft until optics can acquire the landmark.

4.2.4 P23, Cislunar Navigation—CMC

P23 is an onboard navigation program designed to enable updating of the current onboard-estimated state vector in cislunar space. Navigation data needed to make these updates are gathered in P23 during successive star–landmark and star–horizon sextant sightings made by the crew. These sightings measure angles between a selected star and a reference body (earth or moon), landmark, or horizon (Figures 4.2.4-1a and b). The data are then used for recursive updating the state vector and the state-vector error-transition matrix. (Refer to paragraph 4.1.2.) Navigation using P23 is feasible either within the earth- or the lunar-gravitational sphere.*

Normally, the body nearer the vehicle is used as the measurement reference, in order to increase the effects of parallax. Sightings can be taken on the reference body farther from the vehicle if trajectory geometrical considerations make it advantageous. Targets that can be specified generally fall into two categories:

- One of 37 navigation stars whose coordinates are stored in fixed CMC memory.
- A planet or star whose inertial coordinates are available as a function of ephemeris time.

Briefly, P23 events are as follows:

1. Calibration.—The angle θ in Figure 4.2.4-1 is measured as the angle between the landmark line of sight (LLOS) and the star line of sight (SLOS) when the two images appear superimposed in the SXT. The LLOS lies along the fixed shaft axis and is positioned by maneuvering the spacecraft. The SLOS, discounting error, lies along the trunnion and is positioned by the optics hand controller (OHC). A 0-deg trunnion angle results when there is no instrument error and the LLOS and SLOS are parallel. Therefore, to calibrate the optics, the LLOS is pointed at a calibration feature, e.g., a star, and the SLOS is then positioned such that two images of the same feature appear superimposed. Upon the crew's MARK, θ is stored as trunnion bias to be applied to subsequent MARK data.

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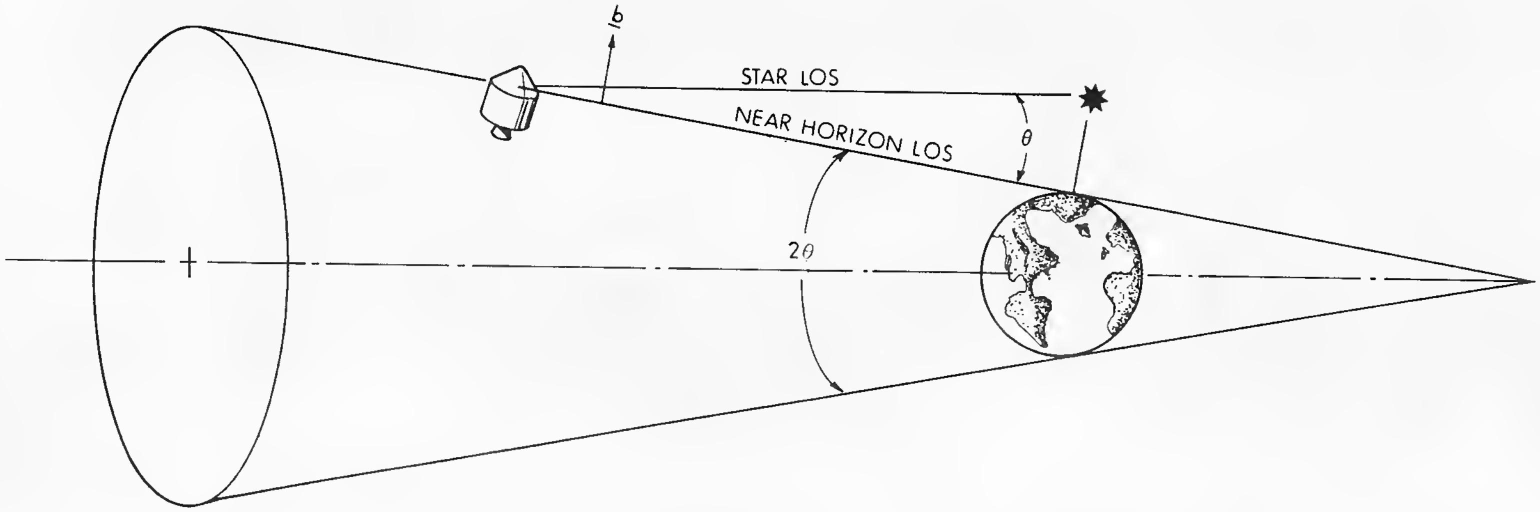
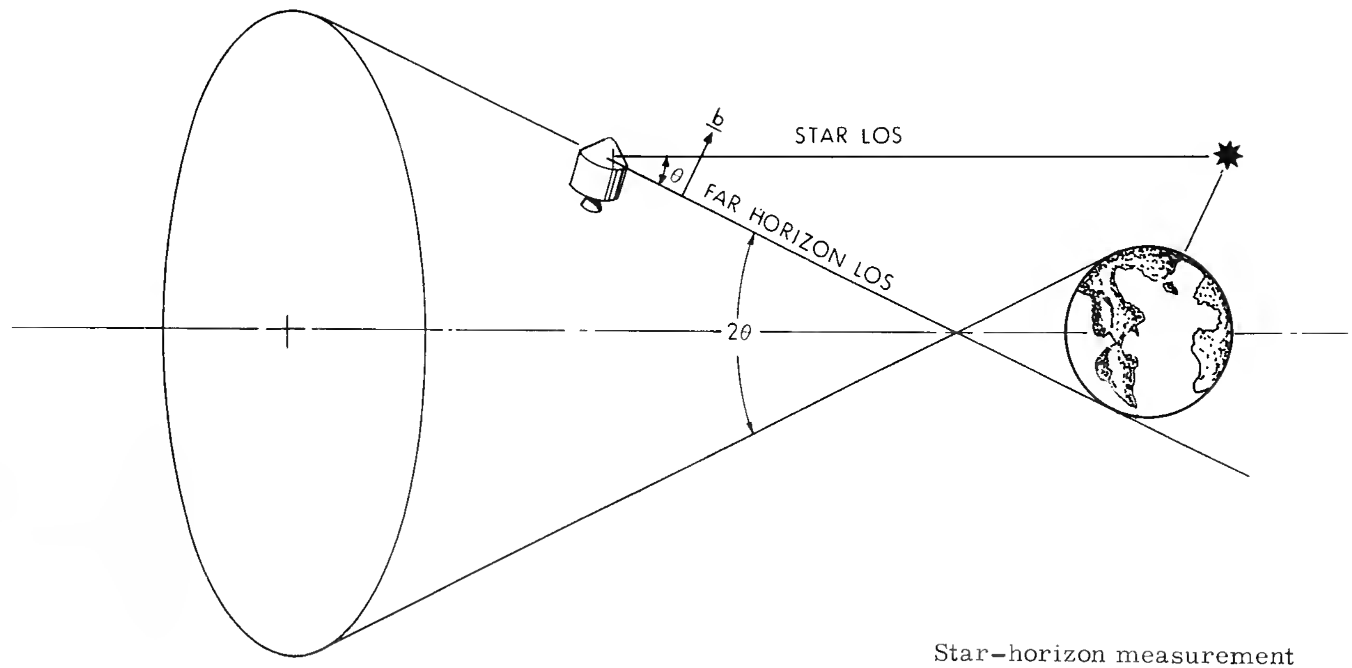
*Since P37 uses state-vector data compiled by P23, it is noteworthy that P37 requires a t_{IG} outside the lunar sphere.



Star–horizon measurement showing measured angle (θ), $\underline{b}$ vector, and measurement cone of revolution (2θ) for (a) near-horizon and (b) far-horizon geometry

Figure 4.2.4-1a. Star–Horizon Measurement Geometry (Near-horizon)



Star–horizon measurement showing measured angle (θ), $\underline{b}$ vector, and measured cone of revolution (2θ) for (a) near-horizon and (b) far-horizon geometry.

Figure 4.2.4-1b. Star–Horizon Measurement Geometry (Far-horizon)

NOTE.—In some instances, it is possible for the center line of the SLOS to be noncoincident with the LLOS when the trunnion angle is zero (i.e., boresight error normal to shaft drive axis and parallel to the trunnion drive axis). Although a small boresight error of this kind would yield acceptable MARK data, the crew would not be able to effect actual superimposition of the two lines of sight during calibration. In that instance, he should take a calibration MARK when the two images lie along a line normal to the shaft axis:

(exaggerated example of proper sight picture for zero trunnion angle with SLOS–LLOS boresight error).

2. Navigation Measurement.—When the SXT has been calibrated, the crew selects a planet or star and a suitable substellar point (Figure 4.2.4-2), maneuvers the spacecraft and positions the optics to superimpose the two images, and depresses the MARK button. The CMC records the measurement data and computes a state-vector update according to the principles of recursive navigation discussed in paragraph 4.1.2.

3. Incorporation of Update.—The magnitude of the update is displayed for the crew to accept or reject according to pad criteria.

Options available to the crew are described in paragraph 4.2.4.1. Paragraph 4.2.4.2 is a step-by-step description of P23 procedures. Finally, paragraphs 4.2.4.3–4.2.4.8 contain added information regarding (4.2.4.3) Influence of Measurement Geometry on State Vector; (4.2.4.4) Post-measurement Evaluation; (4.2.4.5) Effects of Calibration and Substellar Pointing-angle Errors; (4.2.4.6) Marking on the Horizon; (4.2.4.7) W-matrix; (4.2.4.8) Typical Tracking Schedule.

4.2.4.1 Options

The cislunar navigation program was originally designed for operation during IMU power-down. The entire navigation-sighting procedure, therefore, was to be performed manually—placing a considerable burden on the navigator. Manual attitude maneuvering of the vehicle to the landmark or horizon while maintaining star acquisition—manually—is quite difficult; maintaining vehicle attitude while acquiring the star is equally difficult. Possible results are high fuel consumption and erroneous state-vector updates. These and other considerations led to the decision to leave, normally, the IMU on during cislunar flight.*

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*For a more detailed explanation of cislunar navigation and the development thereof in APOLLO, read "Manually-aided Onboard APOLLO Cislunar Navigation," by P. Brennan and I. Johnson, June 1970.

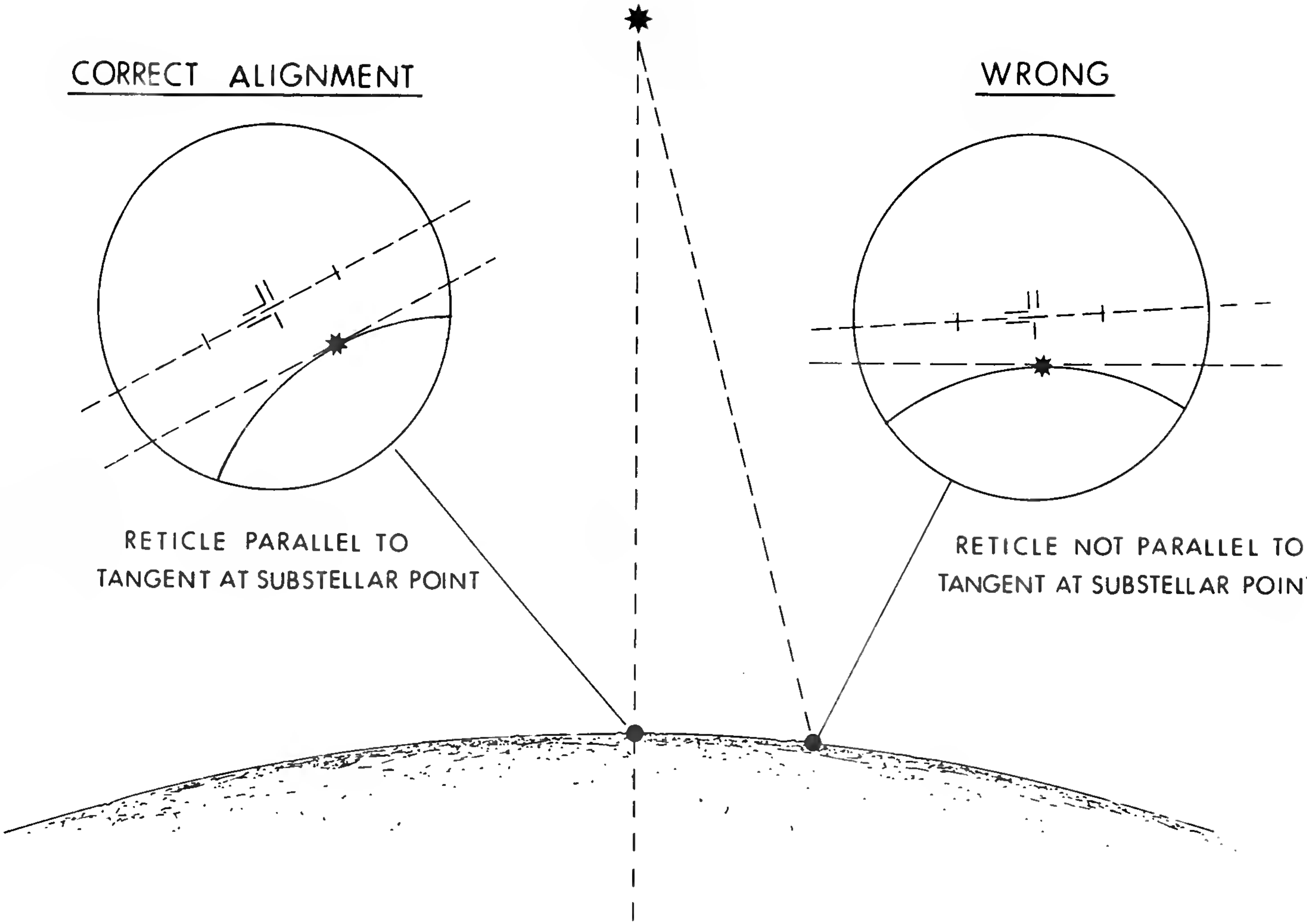

Figure 4.2.4-2. Correct Reticle Alignment with Substellar Tangent

IMU availability now enables star acquisition by CMC-controlled drive of the sextant SLOS to the target designated by the crew. CMC-controlled attitude maneuvers to the computed substellar point or to the designated landmark are also possible. Should it be necessary, however, for the navigator to perform manual maneuvers to tracking attitudes and optics positioning, he can still do so. (See paragraph 4.2.4.2.)

4.2.4.1.1 Landmark Option.—Though available, the option to designate earth and lunar landmarks for marktaking by specifying the latitude, longitude, and altitude of each, is little used. The star-horizon measurement option has largely supplanted star-landmark sightings because adequate landmarks are not always available and because star-image visibility is usually marginal against a bright earth image. (See NOTES 1 and 2 below.) The VERB 06 NOUN 89 landmark latitude-longitude-altitude display appears only if the unstored known-landmark option is loaded in the target identification display.

4.2.4.1.2 Planet Option.—Another P23 option is the capability of selecting planets (e.g., Mars, Venus) for navigation by specifying the x, y, and z basic-reference components of their locations at a particular GET to the CMC via the VERB 06 NOUN 88 DSKY display. Unlike the 37 navigation stars, whose inertial coordinates are fixed and can be stored in the CMC by star code, planet ephemerides are time varying and must be obtained from precalculated tables (carried onboard) for the desired measurement time.

NOTE 1.—Use of earth landmarks or the lunar disk for calibration has also been deemphasized in favor of star calibration. P23 now provides an option for automatically maneuvering the spacecraft (by R60) to point the SXT landmark line of sight (LLOS) at a star for calibrating trunnion bias. (Refer to paragraph 4.2.4.2, "Procedures.")

NOTE 2.—Near the earth, earth light scattered in the optics tends to obscure stars in its vicinity. This may reduce the population of stars available for navigation angle measurements to three or four situated more than 30 deg from the earth horizon LOS; i.e., in the outer periphery of the 100-deg cone covered by the SXT trunnion. Because the earth's image is much brighter than that of a star, the optics LLOS was designed to transmit only 3.2 percent of incident light and the SLOS to transmit about 25 percent to ensure appropriate differential visibility for star-horizon superimposition. Because of the 25-fold incident light attenuation through the LLOS and the fact that earthshine tends to swamp star images near the earth, calibration may require maneuvers to attitudes that point the LLOS 20 or 30 deg from the earth. At the 0.2-deg/sec DAP rate, calibration maneuvers may require several minutes. Thus a trade must be made between frequent calibration (which ensures low-measurement bias and precise navigation), time, and RCS fuel consumption.

TABLE 4.2.4-I.

CISLUNAR NAVIGATION PROGRAM (CMC P23)

DSKY PROCEDURES (SHEET 1 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
1	V37E 23E	FL V50 N25* (R57)	P23	Request "Please perform celestial-body acquisition"	R1 00015 Checklist code R2 Blank R3 Blank	• Reset RNDVZFLG • Reset RENDWFLG • Reset SAVECFLG • Upon crew's PRO, proceed to next step; upon crew's ENTR, go to step 7.	•If CMC maneuver to point the LLOS at selected star is desired, key PRO. •If manual maneuver is desired, key ENTR and maneuver S/C to acquire suitable star in the SXT FOV; go to step 7. •If no maneuver is desired, key ENTR and go to step 7.	*Occurs only if IMU is on and aligned (REFSMFLG set); otherwise, program begins at step 7 and omits steps 9–16.
2	---	FL V01 N70** (R57)	P23	Display octal code of celestial-body desired for use in calibration.	R1 oooxx Code R2 Blank R3 Blank where xx is— 00_8 = any planet 01_8–45_8 = star from celestial body list 46_8 = sun 47_8 = earth 50_8 = moon	•Accept new data •Upon crew's PRO (xx = 00_8), proceed to next step; upon crew's PRO (xx = 01_8–45_8), obtain star vector from storage, correct for aberration, reset 3AXISFLG, and proceed to step 4; upon crew's PRO (xx = 46_8, 47_8, 50_8), calculate vector for the designated body, reset 3AXISFLG, and proceed to step 4.	•Load (V21E) desired code •When satisfied with code, key PRO	**Occurs only if crew keys PRO to step 1; otherwise, program proceeds to step 7.
3	---	FL V06 N88*** (R57)	P23	Display planet position vector at GET.	R1±.xxxxx XPL R2±.xxxxx YPL R3±.xxxxx ZPL	•Accept new data •Upon crew's PRO, reset 3AXISFLG, and proceed to next step.	•Load (V25E) desired data •When satisfied with data, key PRO	***Occurs only if NOUN 70 (R1) contains 00000; otherwise program proceeds to step 4.
4	---	FL V50 N18 (R60)	P23	Display desired final gimbal angles and request "Please perform auto maneuver"	R1+xxx.xx deg OGA R2+xxx.xx deg IGA R3+xxx.xx deg MGA	•Upon crew's PRO, proceed to next step. •Upon crew's ENTR, exit R60 and proceed to step 7. •Upon crew's V34E, do R00 and exit R60.	•To perform automatic maneuver— (1) set SC CONT to CMC (2) set CMC MODE to AUTO (3) key PRO •To perform maneuver manually, use RHC, referencing out the window or the FDAI Ball and attitude error needles. Key ENTR.	NOTE. —Final vehicle attitude is calculated using VECPOINT (3AXISFLG reset). Attitude about body-fixed vector is unconstrained

TABLE 4.2.4-I.

CISLUNAR NAVIGATION PROGRAM (CMC P23)

DSKY PROCEDURES (SHEET 2 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
5	---	V06 N18 (R60)	P23	Display final gimbal angles during automatic maneuver.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	•Perform maneuver •When maneuver terminates or is interrupted, proceed to next step.	•Monitor •If maneuver approaches gimbal lock, use RHC to complete maneuver manually—referencing out the window or FDAI Ball and attitude-error needles.	Maneuver rate will be that last prescribed by the crew (R03). If MGA=±75 deg occurs, maneuver will terminate and enter ATT HOLD. Program proceeds to next step. Crew must use RHC to maneuver around gimbal lock.
6	---	FL V50 N18 (R60)	P23	Display desired final gimbal angles and request "Please perform auto maneuver."	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	•Upon crew's PRO, recycle maneuver. •Upon crew's ENTR, exit R60 and proceed to next step. •Upon crew's V34E, do R00 and exit R60.	•To recycle maneuver, key PRO. •To proceed to step 7, key ENTR (present attitude and displayed gimbal angles agree—within deadband limits).	---
7	---	FL V59† (R57)	P23	Request "Please perform calibration mark."	R1 Blank R2 Blank R3 Blank	•Upon crew's MARK, store trunnion OCDU angle and proceed to step 8. •Upon crew's ENTR, exit R57 and proceed to step 9 (REFSMFLG set) or to step 17 (REFSMFLG reset).	•To perform optics-calibration check— (1) set OPT ZERO to OFF (2) set OPT SPEED to LO (3) set OPT MODE to MAN (4) set OPT TELTRUN to SLAVE to SXT (5) set OPTICS COUPLING to DIR (6) Use MIC to center calibration feature in SXT (7) Use OHC to superimpose SLOS on LLOS (8) Depress MARK button •To bypass optics calibration check— (1) set OPTICS MODE to CMC (REFSMFLG set) or to MAN (REFSMFLG reset) (2) Key ENTR	† First P23 display when IMU is not on and aligned; second P23 display if crew keys ENTR to FL V50 N25 (step 1).

TABLE 4.2.4-I.
CISLUNAR NAVIGATION PROGRAM (CMC P23)
DSKY PROCEDURES (SHEET 3 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
8		FL V06 N87 (R57)	P23	Display trunnion bias angle.	R1 Blank R2 xx.xxx deg R3 Blank	•Upon crew's PRO, incorporate the calibration angle and proceed to next step (REFSMFLG set) or to step 17 (REFSMFLG reset). •Upon crew's V32E, return to step 1 (REFSMFLG set) or step 7 (REFSMFLG reset).	• To incorporate the MARK, key PRO. • To recalibrate (1) repeat step 7, and proceed to step 1 (i.e. resight and depress MARK button) (2) key V32E • To load crew-recorded values, key V22N94E, load R2, key PRO	
9		FL V05 N70	P23	Display pre-mark measurement identification.	R1 000DE (star) R2 ABCDE (LMK) R3 00CD0 (HOR) R1 DE = star ID 00_8 = any planet 01_8–45_8 = star from celestial-body list. R2 †† AB not used C = 1 (earth LMK) C = 2 (moon LMK) DE not used R3 †† C = 1 (earth horizon) C = 2 (moon horizon) D = 1 (near horizon) D = 2 (far horizon)	•Accept new data •Upon crew's PRO– (1) proceed to next step if R2 ≠ 00 (landmark) (2) proceed to step 11 if R1 = 00 (planet) and R3 ≠ 00 (horizon) (3) proceed to step 12 if R1 = 01–45 (star code) and R3 ≠ 00 (horizon) (4) turn on OPR ERR if R1 ≠ 00–45 or if R2-R3 are illogically configured.	•Load (V25E) desired data. •Key PRO	†† Either R2 or R3 should be zero, but not both: R2 is zero for horizon measurement; R3 is zero for landmark measurement. NOTE. –steps 9–16 are bypassed if IMU is not on and aligned, i.e., if REFSMFLG is not set.
10		FL V06 N89††† (Star/planet-landmark)	P23	Display landmark data (Longitude is divided by two for scaling.) Legal values in R1 and R2 are 0–90 deg.	R1 ± xx.xxx deg LAT R2 ± xx.xxx deg LONG/2 R3 ± xxx.xx n.mi. ALT "+" is north latitude and east longitude. Altitude is above Fischer ellipsoid (earth) or mean lunar radius (MLR)	•Accept new data •Upon crew's PRO, proceed to next step if NOUN 70 (R1)–step 9–equals zero (planet); proceed to step 12 if NOUN 70 (R1) equals 01–45 (star code).	•Load (V25E) desired data •Key PRO	†††Occurs only if NOUN 70 (R2) not equal to zero (landmark).

TABLE 4.2.4-I.
CISLUNAR NAVIGATION PROGRAM (CMC P23)
DSKY PROCEDURES (SHEET 4 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
11	---	FL V06 N88# (Planet-land-mark/horizon)	P23	Display planet position vector at GET.	R1 + .xxxxx XPL R2 $\mp$ .xxxxx YPL R3 $\mp$ .xxxxx ZPL	•Accept new data •Upon crew's PRO, integrate CSM state vector to present time, calculate the attitude required to point the LLOS at the horizon or landmark, proceed to next step.	•Load (V25E) desired data •Key PRO	#Occurs only if NOUN 70 (R1) = 00 (planet)
12	---	FL V50 N25	P23	Request "Please perform three-axis automatic maneuver to tracking attitude."	R1 00202 R2 Blank R3 Blank	•Upon crew's PRO, calculate the desired gimbal angles for a three-axis maneuver. Set 3AXISFLG and proceed to next step. •Upon crew's ENTR, use VECPOINT to calculate desired gimbal angles, reset 3AXISFLG, and proceed to next step.	•To perform three-axis maneuver, key PRO. •To perform VECPOINT maneuver, key ENTR.	
13	---	FL V50 N18 (R60)	P23	Display desired final gimbal angles and request "Please perform automatic maneuver" to tracking attitude.	R1 + xxx.xx deg OGA R2 + xxx.xx deg IGA R3 + xxx.xx deg MGA	•Upon crew's PRO, proceed to next step. •Upon crew's ENTR, exit R60, set V94FLAG, and proceed to step 16. •Upon crew's V34E, do R00 and exit R60.	•To perform automatic maneuver— (1) set SC CONT to CMC (2) set CMC MODE to AUTO (3) key PRO •To perform maneuver manually, use RHC, referencing out the window or the FDAI Ball and attitude-error needles. •To load ground-computed angles (three-axis), key V25N22E, load data, then perform the maneuver.	NOTE. —If crew keyed PRO in response to FL V50 N25 (R1, 00202)—step 12—gimbal angles correspond to desired three-axis tracking attitude and present IMU orientation. NOTE. —Although a three-axis maneuver is desirable, it may produce gimbal lock (Alarm 00401). Should, upon a PRO response to FL V50 N25 (R1, 00202), an Alarm 00401 occur, clear the alarm and key ENTR to FLV50N18. If crew keyed ENTR in response to step 12, gimbal angles correspond to VECPOINT calculations—vehicle attitude about pointing vector unconstrained.

TABLE 4.2.4-I.

CISLUNAR NAVIGATION PROGRAM (CMC P23)

DSKY PROCEDURES (SHEET 5 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
14	---	V06 N18 (R60)	P23	Display desired final gimbal angles during automatic maneuver.	R1+xxx.xx deg OGA R2+xxx.xx deg IGA R3+xxx.xx deg MGA	•Perform maneuver. •When maneuver terminates or is interrupted, proceed to next step.	•Monitor •If maneuver approaches gimbal lock, use RHC to complete the maneuver manually—referencing out the window or FDAI Ball and attitude-error needles.	Maneuver rate will be that last prescribed by crew (R03). If MGA = ±75 deg occurs, maneuver will terminate and enter ATT HOLD. Program proceeds to next step. Crew must use RHC to maneuver around gimbal lock.
15	---	FL V50 N18 (R60)	P23	Display desired final gimbal angles and request "Please perform auto maneuver."	R1+xxx.xx deg OGA R2+xxx.xx deg IGA R3+xxx.xx deg MGA	•Upon crew's PRO, recycle maneuver. •Upon crew's ENTR, exit R60, set V94FLAG, and proceed to next step. •Upon crew's V34E, do R00 and exit R60.	•To recycle maneuver, key PRO. •To proceed to step 16, key ENTR (present attitude and displayed gimbal angles agree within deadband limits).	---
16	---	V06 N92 (R52)	P23	Nonflashing display of desired shaft and trunnion angles.	R1+xxx.xx deg shaft R2+xx.xxx deg trunnion R3 blank	•Reset Sighting Mark Flag •Get present IMU orientation from storage (REFSMMAT). •Read present vehicle attitude from ICDUs. •Get star/landmark data from CMC storage •Compute target vector from CSM to star/landmark •Calculate the required optics angles to point the SLOS along the target vector •Display Alarm 00404 if target is not within optics cone of acquisition (COA). •If target within COA and the required trunnion angle is ≤ 49.775 deg, drive shaft and trunnion CDUs to acquire target; if required trunnion CDU is >49.775 deg, drive shaft CDU and drive trunnion CDU to 49.775 deg. •Upon crew's setting OPTICS MODE switch to MAN, proceed to next step and continue to recycle R52 until terminated by R53.	•Monitor •When target is acquired, set OPT MODE switch to MAN.	Possible Alarm FL V05 N09 R1, R2 or R3—00404 (target not within 90 deg COA). Either manually maneuver S/C to reduce required trunnion angle or terminate program (V34E). If manual maneuver is performed successfully, key PRO—two-second delay required after priority display. NOTE.—V94E can be used to terminate R52/R53 anytime before MARK acceptance. If crew keys V94E after a MARK but before accepting it, the MARK data will be lost.

TABLE 4.2.4-I.

CISLUNAR NAVIGATION PROGRAM (CMC P23)

DSKY PROCEDURES (SHEET 6 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
17	---	FL V51 (R53)	P23	Request "Please MARK."	R1 Blank R2 Blank R3 Blank	•Set Sighting Mark Flag, and set Mark Index = 1 •Upon crew's MARK, set MARKFLAG, store mark data, and decrement Mark Index by one. •Go to next step when Mark Index = 0.	To MARK— (1) Set OPT COUPLING to RSLV (2) Set OPT SPEED to LO (3) Use MIC to position substellar point near center of SXT FOV (Fig. 4.2.4-2). (4) Use OHC to superimpose star/planet on substellar point (Fig. 4.2.4-2). (5) MARK	Possible Alarm PROG Alarm 00110 (MARK REJ depressed when no MARK has been taken). Key RSET and proceed to take MARK if desired.
18	---	FL V50 N25 (R53)	P23	Request "Please Terminate mark sequence."	R1 00016 R2 Blank R3 Blank	•Upon crew's MARK REJ, erase last set of mark data and increment MARK counter by one. Reset Mark Flag and return to step 17.* •Upon crew's PRO, reset Mark Flag, set Terminate Flag, exit R53, reset V94FLAG, and proceed to next step. Upon crew's PRO, set SAVECFLG (indicating that a mark has been taken)	•To accept MARK data and proceed to next step, key PRO. •To reject MARK and return to FL V51, key MARK REJ.* •To terminate R52–R53 and return to step 12, key V94E. •To terminate R52–R53 and P23, key V34E or V37E xxE.	NOTE. —Should crew key V94E, V34E, or V37E xxE before accepting mark data (PRO to FL V50 N25, R1 = 00016), the data will be lost. *NOUN 25 (R1, 00016) remains.
19	---	FL V05 N71	P23	Display post-mark measurement identification.	R1 000DE (star) R2 ABCDE (LMK) R3 00CD0 (HOR) R1 DE = star ID 00_8 = any planet 01_8–45_8 = star from celestial-body list R2## AB not used C = 1 (earth LMK) C = 2 (moon LMK) DE not used R3## C = 1 (earth horizon) C = 2 (moon horizon) D = 1 (near horizon) D = 2 (far horizon)	•Accept data •Upon crew's PRO— (1) If R2 ≠ 00 (landmark), proceed to next step. (2) If R1 = 00 (planet), and and R3 ≠ 00 (horizon), proceed to step 21. (3) If R1 = 01–45 (star-code), and R3 ≠ 00 (horizon), proceed to step 22. (4) Turn on OPR ERR if R1 ≠ 00–45 or if R2–R3 are illogically configured.	IMU on and aligned (REFSMFLG set) •Verify data •Key PRO IMU not on or not aligned (REFSMFLG reset) •Load data (V25E) for measurement performed. •Key PRO	##Either R2 or R3 should be zero, but not both: R2 is zero for horizon measurement; R3 is zero for landmark measurement. NOTE. —NOUN 71 contains values originally loaded into NOUN 70—step 9 (REFSMFLG set). If step 9 was bypassed (REFSMFLG reset), the appropriate data for the measurement performed in step 17 must now be loaded.

TABLE 4.2.4-I.
CISLUNAR NAVIGATION PROGRAM (CMC P23)
DSKY PROCEDURES (SHEET 7 OF 7)

No.	Entry Point •	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
20	---	FL V06 N89### (star/planet-landmark)	P23	Display landmark data (Longitude is divided by two for scaling. Legal values in R1 and R2 are 0–90 deg).	R1 ± xx.xxx deg LAT R2 ± xx.xxx LONG/2 R3 + xxx.xx n.mi. − ALT "+" is north latitude and east longitude. Altitude is above Fischer ellipsoid (earth) or MLR (moon).	•Accept data •Upon crew's PRO, proceed to next step if NOUN 71 (R1)–step 19–equals zero (planet); proceed to step 22 if NOUN 71 (R1) equals 01-45 (star code).	IMU on and aligned (REFSMFLG set) •Verify data •Key PRO IMU not on or not aligned (REFSMFLG reset) •Load data (V25E) for measurement performed. •Key PRO.	###Occurs only if NOUN 71 (R2) not equal to zero (landmark)
21	---	FL V06 N88*# (Planet-landmark/horizon)	P23	Display planet position vector at MARK GET.	R1 ± .xxxxx XPL R2 ± .xxxxx YPL R3 ± .xxxxx ZPL	•Accept data •Upon crew's PRO, proceed to next step.	IMU on and aligned (REFSMFLG set) •Verify data •Key PRO IMU not on and aligned •Load data (V25E) for measurement performed. •Key PRO	*#Occurs only if NOUN 71 (R1) equals zero (planet).
22	---	FL V06 N49	P23	Display state vector changes.	R1 + xxx.xx n.mi. ΔR R2 + xxxx.x ft/sec Δv R3 Blank ΔR is magnitude of position-vector change. Δv is magnitude of velocity-vector change.	•Compute and display state-vector change due to measurement. •Upon crew's V32E, do R00. •Upon crew's PRO, update CMC state vector, and do R00.	•To accept update, key PRO. •To reject update, key V32E.	---
23	---	FL V37 (R00)	P23	Request "Please select new program."	---	---	•To reselect P23, key 23E. •To select Pxx, key xxE.	---

4.2.4.2 Procedures

Table 4.2.4-I is a summary of P23 DSKY procedures. An amplified description is presented here.

1. After preliminary procedures have been performed as prescribed by the appropriate mission documentation, initiate the Cislunar Navigation Program (P23) by keying VERB 37 ENTR 23 ENTR. Observe flashing display of Checklist code requesting "Please perform celestial-body acquisition:"

   FL VERB 50 NOUN 25 (R57)

R1	00015	Checklist Code
R2	Blank	
R3	Blank	

   NOTE.—FL VERB 50 NOUN 25 does not occur if the IMU is not on and aligned. If IMU is not on and aligned (REFSMFLG reset), P23 begins at step 7 and omits steps 9–16.

   If a CMC maneuver to point the LLOS at the selected star is desired, key PRO.

   NOTE.—If no maneuver is desired, key ENTR and proceed to step 7; if a manual maneuver is desired, key ENTR, manually maneuver the spacecraft to acquire a suitable star in the SXT FOV, and proceed to step 7. (See, however, paragraph 4.2.4.1.)

2. Observe flashing display of the octal code designating the celestial body to be used in calibrating the optics (not preloaded):

   FL VERB 01 NOUN 70 (R57)

R1	000xx	Code
R2	Blank	
R3	Blank	

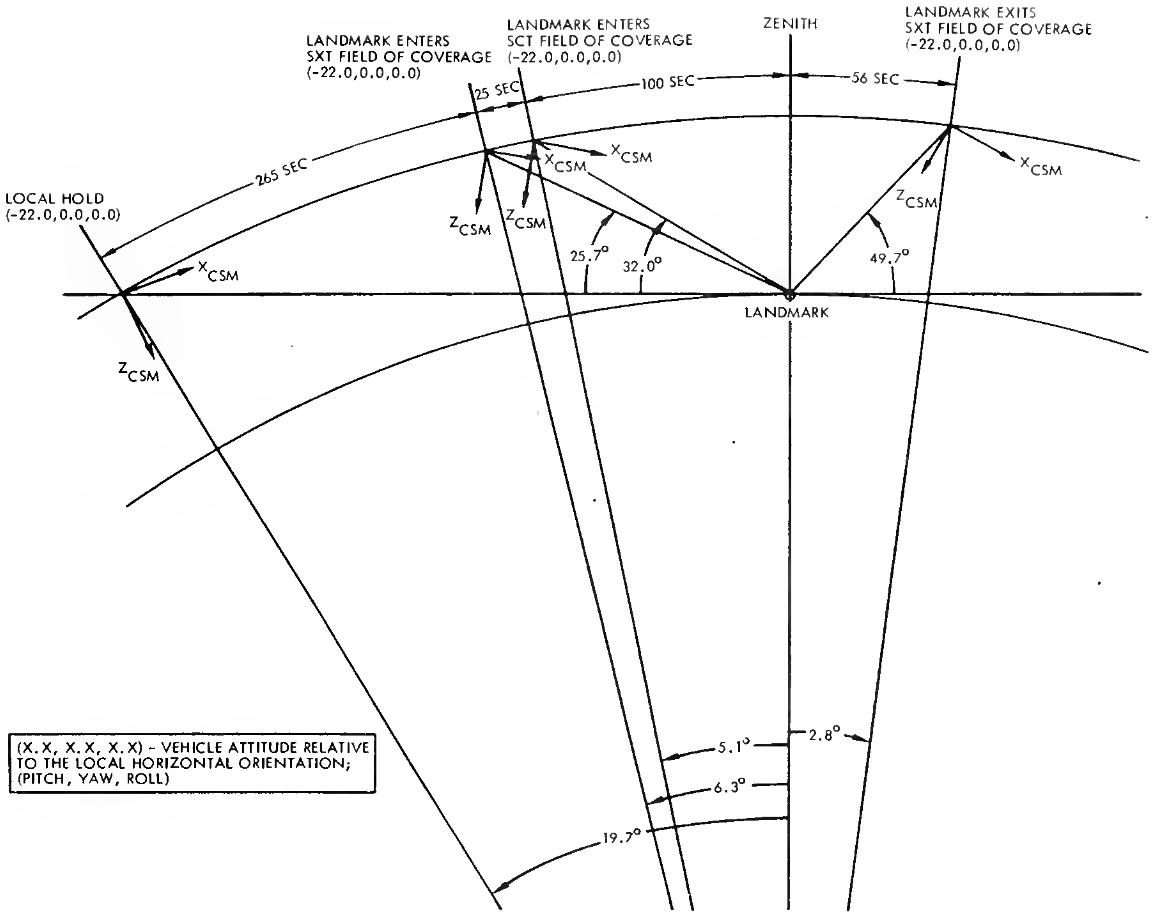

Figure 4.2.3 -5. Tracking Geometry for Mode III Undocked Landmark Tracking (CSM P22)

4.2.3.3 Acquisition Attitudes and Marktaking Pitch Rates

The principal decisions that must be made in P22, as it is currently used, are the selection of the extended verbs and routines required to obtain the desired attitude and pitch rate—with particular emphasis on the timing and magnitude of rates and maneuvers. The two fundamental tracking modes, with several variations, involve various combinations of vehicle attitude and pitch rate, depending on whether marks are to be taken in the docked or undocked configuration and on the size of the acquisition and marktaking windows required.

Maneuvers to inertial acquisition and tracking attitudes can be performed using the Crew Defined Maneuver Routine, R62, obtained by keying VERB 49. Attitude rates can be obtained by a number of alternative methods. Orbrate (-0.05 deg/sec) can be attained by loading a minimum rate into the DAP and commanding a maneuver to an attitude sufficiently far (e.g., 45 deg) from the initial attitude that it will not be reached during the marktaking interval, so that the vehicle will continue to pitch at orbrate while the landmark is acquired and marks are taken.

After the landmark has been acquired, the Minimum Impulse Controller can be used, in the CMC FREE position, to impose a pitch rate prior to marktaking. Option 2 of the Universal Tracking and Rendezvous Navigation Program (P20, paragraph 4.2.1) is also available for initiating a constant-rate pitch maneuver that will keep the landmark within the SXT FOV.

4.2.3.4 Preliminary Procedures

The IMU is aligned via P52 as near to the time landmark tracking begins as is convenient—usually about 1 hour before P22 is entered. The landing site alignment used is that in which the stable member X-axis is aligned to the landing site local vertical. To obtain the 22-deg nosedown, 10-deg left roll acquisition attitude defined above, key VERB 49E and load R1, R2 and R3 in the NOUN 22 display with 10 deg, 248 deg and 0 deg, respectively (248 deg represents a 112-deg pitch down from the landmark local vertical).

In the H1-mission, the attitude required for acquisition was computed and the P22 PAD voiced up immediately before the VERB 49 maneuver to the acquisition attitude. In the G-mission the maneuver PAD was transmitted 45 minutes to an hour ahead because the landing site was farther east and there was insufficient time for tracking and computation of new PAD values before the maneuver. For westerly landing sites, the CSM can be tracked through the period after communication is reestablished,

less than an hour before the maneuver. In this way state-vector information with the smallest possible extrapolation and potential modeling errors can be incorporated into the computed VERB 49 roll, pitch and yaw values.

The VERB 49 manuever to the inertial hold attitude that produces the -2.1-degree attitude specified at the -90-second pitchdown point (Figure 4.2.3-4), can be performed 10 minutes or more in advance.* This allows time to enter P20 early, set up option 2 to initiate pitchover at the appropriate time, and then call P22. (See Table 4.2.3-II.) At the time specified in P20, the pitch maneuver is initiated automatically. Meanwhile, auto optics is tracking the landmark, and the astronaut is monitoring with the SXT. At an elevation angle of +55 deg, and with a -0.3 deg/sec pitch rate, the vehicle angular rate very nearly matches the LOS rate (0.34 deg/sec). Switching to manual optics control at this time is, therefore, desirable since minimal OHC maneuvers are required of the astronaut.

4.2.3.5 Alarms

When the PROG alarm light on the DSKY is illuminated, either VERB 05 NOUN 09 will be displayed automatically with R1, R2, or R3 containing the alarm code, or the crew can have the code displayed by keying VERB 05 NOUN 09 into the DSKY. The crew can then identify and correct the alarm condition and key RSET to continue. A list of alarms that may be encountered in P22 and an explanation of each follows:

a. Alarm 00110 indicates that the MARK REJECT pushbutton has been depressed when no mark to reject. Key RSET to extinguish PROG light. Continue normal operation.

b. Alarm 00115 indicates that V41N91 was keyed when the OPT MODE switch was not in the CMC setting. (The OPR ERR light also illuminates for this alarm.) Set the OPT MODE switch to CMC, and the OPT ZERO switch to OFF.

c. Alarm 00116 indicates that the OPT ZERO switch was taken out of the ZERO setting before the 15-sec–zero-time elapsed. Set OPT ZERO switch to ZERO setting for 15 sec.

d. Alarm 00120 indicates that optics torque has been requested, but that optics have not been zeroed since last freshstart or restart. Set the OPT ZERO switch to OFF, then to ZERO for approximately 15 sec.

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* The convention in the illustrations (pitch, roll, yaw) is not consistent with the roll, pitch, yaw convention used in loading R1, R2 and R3 in VERB 49, and also omits the 10-degree roll, and the use of inertial landmark local vertical coordinates.

e. Alarm 00121 indicates that spacecraft attitude rates are too great, resulting in an automatic rejection of the mark. Repeat mark.

f. Alarm 00210 indicates that the inertial subsystem (ISS) is not on. Re-do the ISS turn-on procedures. If alarm recurs, perform freshstart via VERB 36. Consult MSFN.

g. Alarm 00220 indicates that the IMU orientation is unknown. Align the IMU. If aligned, set REFSMMAT flag.

h. Alarm 00404 indicates that a trunnion angle greater than 90 deg is required to acquire the star or landmark. Maneuver spacecraft until optics can acquire the landmark.

4.2.4 P23, Cislunar Navigation—CMC

P23 is an onboard navigation program designed to enable updating of the current onboard-estimated state vector in cislunar space. Navigation data needed to make these updates are gathered in P23 during successive star–landmark and star–horizon sextant sightings made by the crew. These sightings measure angles between a selected star and a reference body (earth or moon), landmark, or horizon (Figures 4.2.4-1a and b). The data are then used for recursive updating the state vector and the state-vector error-transition matrix. (Refer to paragraph 4.1.2.) Navigation using P23 is feasible either within the earth- or the lunar-gravitational sphere.*

Normally, the body nearer the vehicle is used as the measurement reference, in order to increase the effects of parallax. Sightings can be taken on the reference body farther from the vehicle if trajectory geometrical considerations make it advantageous. Targets that can be specified generally fall into two categories:

- One of 37 navigation stars whose coordinates are stored in fixed CMC memory.
- A planet or star whose inertial coordinates are available as a function of ephemeris time.

Briefly, P23 events are as follows:

1. Calibration.—The angle θ in Figure 4.2.4-1 is measured as the angle between the landmark line of sight (LLOS) and the star line of sight (SLOS) when the two images appear superimposed in the SXT. The LLOS lies along the fixed shaft axis and is positioned by maneuvering the spacecraft. The SLOS, discounting error, lies along the trunnion and is positioned by the optics hand controller (OHC). A 0-deg trunnion angle results when there is no instrument error and the LLOS and SLOS are parallel. Therefore, to calibrate the optics, the LLOS is pointed at a calibration feature, e.g., a star, and the SLOS is then positioned such that two images of the same feature appear superimposed. Upon the crew's MARK, θ is stored as trunnion bias to be applied to subsequent MARK data.

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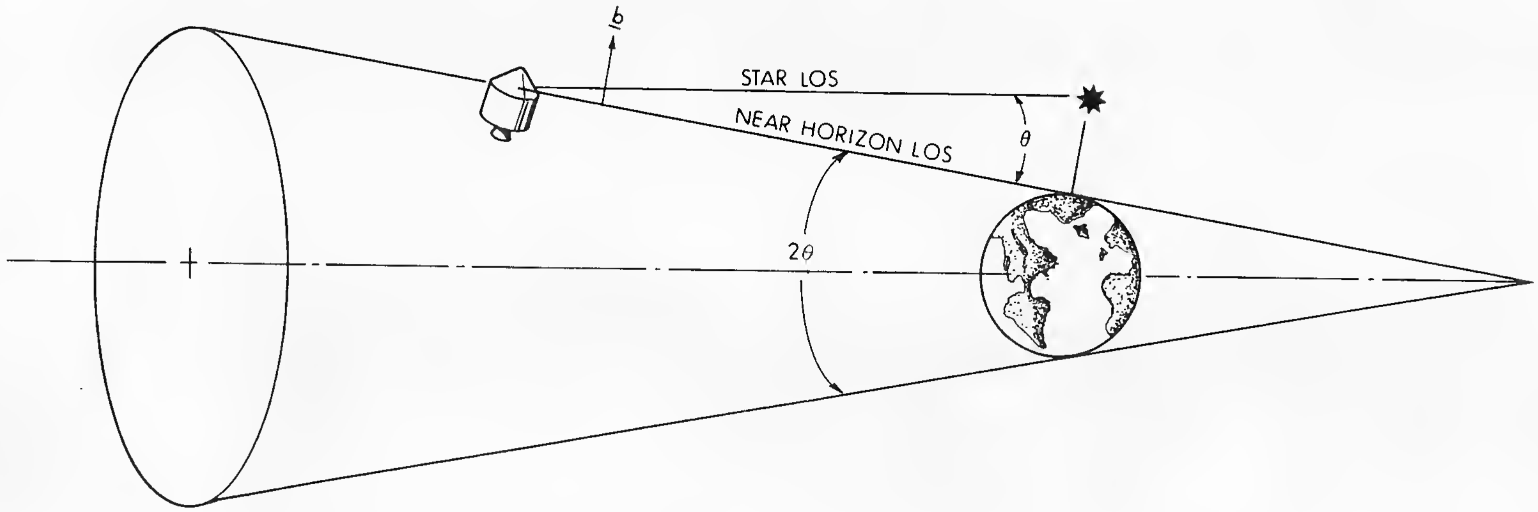
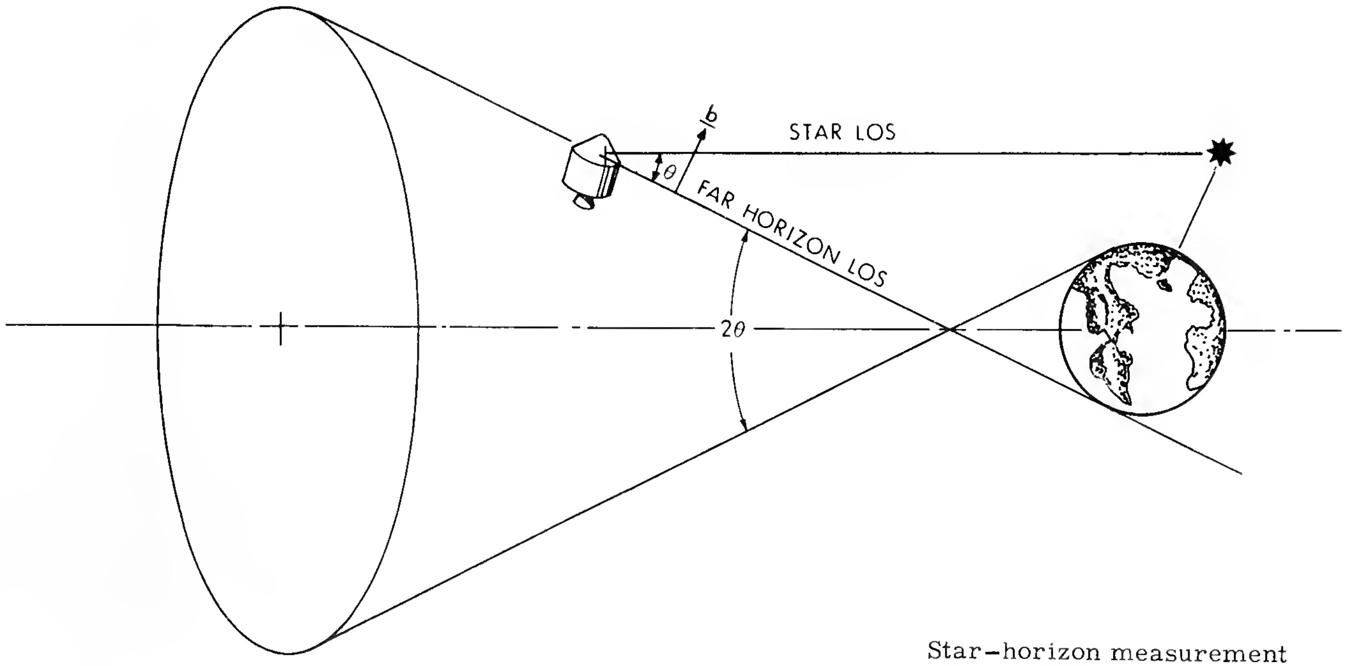
*Since P37 uses state-vector data compiled by P23, it is noteworthy that P37 requires a t_{IG} outside the lunar sphere.



Star–horizon measurement showing measured angle (θ), $\underline{b}$ vector, and measurement cone of revolution (2θ) for (a) near-horizon and (b) far-horizon geometry

Figure 4.2.4-1a. Star–Horizon Measurement Geometry (Near-horizon)



Star–horizon measurement showing measured angle (θ), $\underline{b}$ vector, and measured cone of revolution (2θ) for (a) near-horizon and (b) far-horizon geometry.

Figure 4.2.4-1b. Star–Horizon Measurement Geometry (Far-horizon)

NOTE.—In some instances, it is possible for the center line of the SLOS to be noncoincident with the LLOS when the trunnion angle is zero (i.e., boresight error normal to shaft drive axis and parallel to the trunnion drive axis). Although a small boresight error of this kind would yield acceptable MARK data, the crew would not be able to effect actual superimposition of the two lines of sight during calibration. In that instance, he should take a calibration MARK when the two images lie along a line normal to the shaft axis:

(exaggerated example of proper sight picture for zero trunnion angle with SLOS-LLOS boresight error).

2. Navigation Measurement.—When the SXT has been calibrated, the crew selects a planet or star and a suitable substellar point (Figure 4.2.4-2), maneuvers the spacecraft and positions the optics to superimpose the two images, and depresses the MARK button. The CMC records the measurement data and computes a state-vector update according to the principles of recursive navigation discussed in paragraph 4.1.2.
3. Incorporation of Update.—The magnitude of the update is displayed for the crew to accept or reject according to pad criteria.

Options available to the crew are described in paragraph 4.2.4.1. Paragraph 4.2.4.2 is a step-by-step description of P23 procedures. Finally, paragraphs 4.2.4.3–4.2.4.8 contain added information regarding (4.2.4.3) Influence of Measurement Geometry on State Vector; (4.2.4.4) Post-measurement Evaluation; (4.2.4.5) Effects of Calibration and Substellar Pointing-angle Errors; (4.2.4.6) Marking on the Horizon; (4.2.4.7) W-matrix; (4.2.4.8) Typical Tracking Schedule.

4.2.4.1 Options

The cislunar navigation program was originally designed for operation during IMU power-down. The entire navigation-sighting procedure, therefore, was to be performed manually—placing a considerable burden on the navigator. Manual attitude maneuvering of the vehicle to the landmark or horizon while maintaining star acquisition—manually—is quite difficult; maintaining vehicle attitude while acquiring the star is equally difficult. Possible results are high fuel consumption and erroneous state-vector updates. These and other considerations led to the decision to leave, normally, the IMU on during cislunar flight.[*]

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[*] For a more detailed explanation of cislunar navigation and the development thereof in APOLLO, read "Manually-aided Onboard APOLLO Cislunar Navigation," by P. Brennan and I. Johnson, June 1970.

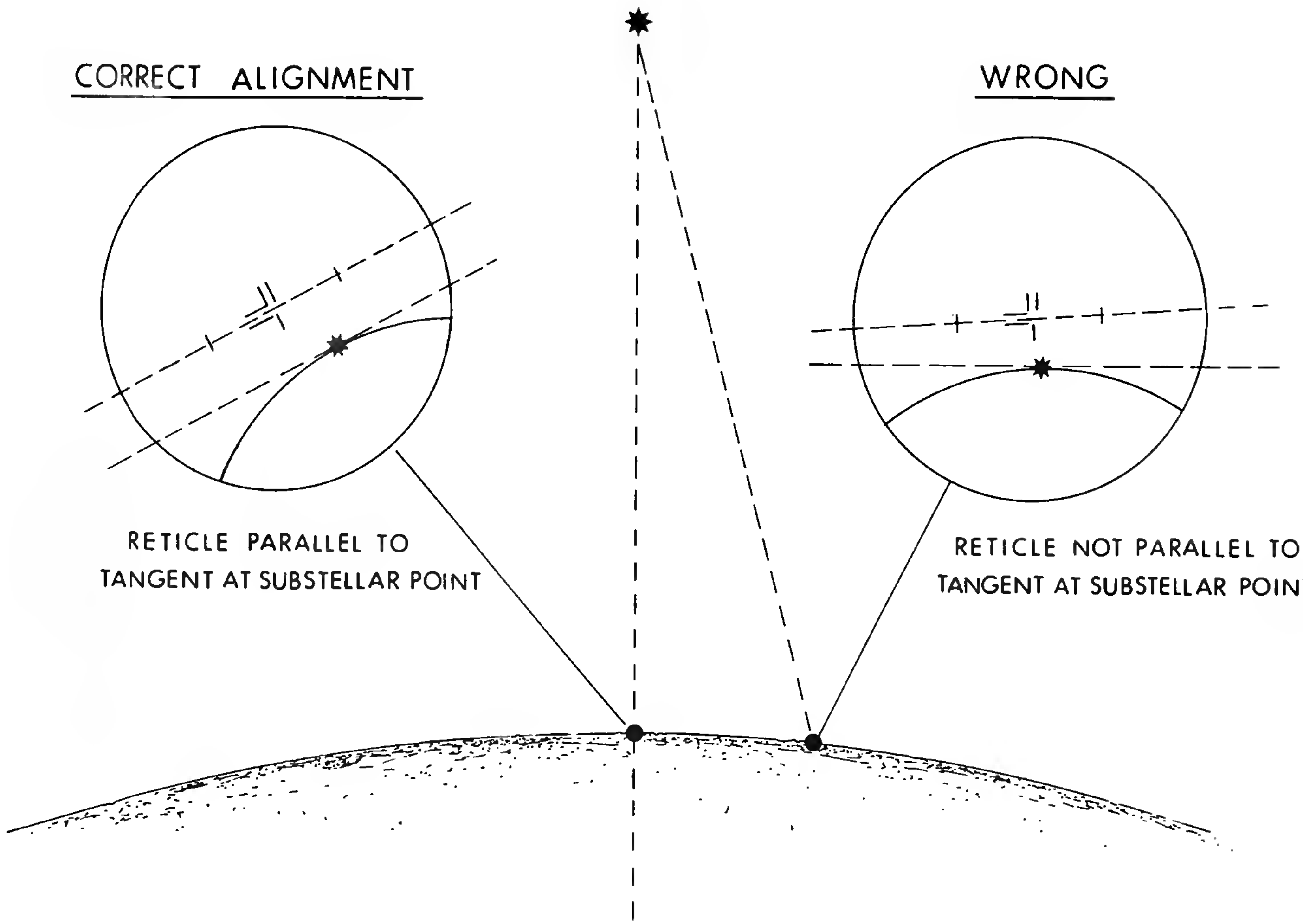


Figure 4.2.4-2. Correct Reticle Alignment with Substellar Tangent

IMU availability now enables star acquisition by CMC-controlled drive of the sextant SLOS to the target designated by the crew. CMC-controlled attitude maneuvers to the computed substellar point or to the designated landmark are also possible. Should it be necessary, however, for the navigator to perform manual maneuvers to tracking attitudes and optics positioning, he can still do so. (See paragraph 4.2.4.2.)

4.2.4.1.1 Landmark Option.—Though available, the option to designate earth and lunar landmarks for marktaking by specifying the latitude, longitude, and altitude of each, is little used. The star–horizon measurement option has largely supplanted star–landmark sightings because adequate landmarks are not always available and because star–image visibility is usually marginal against a bright earth image. (See NOTES 1 and 2 below.) The VERB 06 NOUN 89 landmark latitude-longitude-altitude display appears only if the unstored known-landmark option is loaded in the target identification display.

4.2.4.1.2 Planet Option.—Another P23 option is the capability of selecting planets (e.g., Mars, Venus) for navigation by specifying the x, y, and z basic-reference components of their locations at a particular GET to the CMC via the VERB 06 NOUN 88 DSKY display. Unlike the 37 navigation stars, whose inertial coordinates are fixed and can be stored in the CMC by star code, planet ephemerides are time varying and must be obtained from precalculated tables (carried onboard) for the desired measurement time.

> NOTE 1.—Use of earth landmarks or the lunar disk for calibration has also been deemphasized in favor of star calibration. P23 now provides an option for automatically maneuvering the spacecraft (by R60) to point the SXT landmark line of sight (LLOS) at a star for calibrating trunnion bias. (Refer to paragraph 4.2.4.2, "Procedures,")
>
> NOTE 2.—Near the earth, earth light scattered in the optics tends to obscure stars in its vicinity. This may reduce the population of stars available for navigation angle measurements to three or four situated more than 30 deg from the earth horizon LOS; i.e., in the outer periphery of the 100-deg cone covered by the SXT trunnion. Because the earth's image is much brighter than that of a star, the optics LLOS was designed to transmit only 3.2 percent of incident light and the SLOS to transmit about 25 percent to ensure appropriate differential visibility for star-horizon superimposition. Because of the 25-fold incident light attenuation through the LLOS and the fact that earthshine tends to swamp star images near the earth, calibration may require maneuvers to attitudes that point the LLOS 20 or 30 deg from the earth. At the 0.2-deg/sec DAP rate, calibration maneuvers may require several minutes. Thus a trade must be made between frequent calibration (which ensures low-measurement bias and precise navigation), time, and RCS fuel consumption.

TABLE 4.2.4-I.

CISLUNAR NAVIGATION PROGRAM (CMC P23)

DSKY PROCEDURES (SHEET 1 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
1	V37E 23E	FL V50 N25* (R57)	P23	Request "Please perform celestial-body acquisition"	R1 00015 Checklist code R2 Blank R3 Blank	• Reset RNDVZFLG • Reset RENDWFLG • Reset SAVECFLG • Upon crew's PRO, proceed to next step; upon crew's ENTR, go to step 7.	•If CMC maneuver to point the LLOS at selected star is desired, key PRO. •If manual maneuver is desired, key ENTR and maneuver S/C to acquire suitable star in the SXT FOV; go to step 7. •If no maneuver is desired, key ENTR and go to step 7.	*Occurs only if IMU is on and aligned (REFSMFLG set); otherwise, program begins at step 7 and omits steps 9–16.
2	---	FL V01 N70** (R57)	P23	Display octal code of celestial-body desired for use in calibration.	R1 oooxx Code R2 Blank R3 Blank where xx is— 00_8 = any planet 01_8–45_8 = star from celestial body list 46_8 = sun 47_8 = earth 50_8 = moon	•Accept new data •Upon crew's PRO (xx = 00_8), proceed to next step; upon crew's PRO (xx = 01_8–45_8), obtain star vector from storage, correct for aberration, reset 3AXISFLG, and proceed to step 4; upon crew's PRO (xx = 46_8, 47_8, 50_8), calculate vector for the designated body, reset 3AXISFLG, and proceed to step 4.	•Load (V21E) desired code •When satisfied with code, key PRO	**Occurs only if crew keys PRO to step 1; otherwise, program proceeds to step 7.
3	---	FL V06 N88*** (R57)	P23	Display planet position vector at GET.	R1+.xxxxx XPL R2∓.xxxxx YPL R3∓.xxxxx ZPL	•Accept new data •Upon crew's PRO, reset 3AXISFLG, and proceed to next step.	•Load (V25E) desired data •When satisfied with data, key PRO	***Occurs only if NOUN 70 (R1) contains 00000; otherwise program proceeds to step 4.
4	---	FL V50 N18 (R60)	P23	Display desired final gimbal angles and request "Please perform auto maneuver"	R1+xxx.xx deg OGA R2+xxx.xx deg IGA R3+xxx.xx deg MGA	•Upon crew's PRO, proceed to next step. •Upon crew's ENTR, exit R60 and proceed to step 7. •Upon crew's V34E, do R00 and exit R60.	•To perform automatic maneuver— (1) set SC CONT to CMC (2) set CMC MODE to AUTO (3) key PRO •To perform maneuver manually, use RHC, referencing out the window or the FDAI Ball and attitude error needles. Key ENTR.	NOTE. —Final vehicle attitude is calculated using VECPOINT (3AXISFLG reset). Attitude about body-fixed vector is unconstrained

TABLE 4.2.4-I.
CISLUNAR NAVIGATION PROGRAM (CMC P23)
DSKY PROCEDURES (SHEET 2 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
5	---	V06 N18 (R60)	P23	Display final gimbal angles during automatic maneuver.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	•Perform maneuver •When maneuver terminates or is interrupted, proceed to next step.	•Monitor •If maneuver approaches gimbal lock, use RHC to complete maneuver manually—referencing out the window or FDAI Ball and attitude-error needles.	Maneuver rate will be that last prescribed by the crew (R03). If MGA=$\pm$75 deg occurs, maneuver will terminate and enter ATT HOLD. Program proceeds to next step. Crew must use RHC to maneuver around gimbal lock.
6	---	FL V50 N18 (R60)	P23	Display desired final gimbal angles and request "Please perform auto maneuver."	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	•Upon crew's PRO, recycle maneuver. •Upon crew's ENTR, exit R60 and proceed to next step. •Upon crew's V34E, do R00 and exit R60.	•To recycle maneuver, key PRO. •To proceed to step 7, key ENTR (present attitude and displayed gimbal angles agree—within deadband limits).	---
7	---	FL V59† (R57)	P23	Request "Please perform calibration mark."	R1 Blank R2 Blank R3 Blank	•Upon crew's MARK, store trunnion OCDU angle and proceed to step 8. •Upon crew's ENTR, exit R57 and proceed to step 9 (REFSMFLG set) or to step 17 (REFSMFLG reset).	•To perform optics-calibration check— (1) set OPT ZERO to OFF (2) set OPT SPEED to LO (3) set OPT MODE to MAN (4) set OPT TELTRUN to SLAVE to SXT (5) set OPTICS COUPLING to DIR (6) Use MIC to center calibration feature in SXT (7) Use OHC to superimpose SLOS on LLOS (8) Depress MARK button •To bypass optics calibration check— (1) set OPTICS MODE to CMC (REFSMFLG set) or to MAN (REFSMFLG reset) (2) Key ENTR	† First P23 display when IMU is not on and aligned; second P23 display if crew keys ENTR to FL V50 N25 (step 1).

TABLE 4.2.4-I.
CISLUNAR NAVIGATION PROGRAM (CMC P23)
DSKY PROCEDURES (SHEET 3 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
8		FL V06 N87 (R57)	P23	Display trunnion bias angle.	R1 Blank R2 xx.xxx deg R3 Blank	•Upon crew's PRO, incorporate the calibration angle and proceed to next step (REFSMFLG set) or to step 17 (REFSMFLG reset). •Upon crew's V32E, return to step 1 (REFSMFLG set) or step 7 (REFSMFLG reset).	• To incorporate the MARK, key PRO. • To recalibrate (1) repeat step 7, and proceed to step 1 (i.e. resight and depress MARK button) (2) key V32E • To load crew-recorded values, key V22N94E, load R2, key PRO	
9		FL V05 N70	P23	Display pre-mark measurement identification.	R1 000DE (star) R2 ABCDE (LMK) R3 00CD0 (HOR) R1 DE = star ID 00_8 = any planet 01_8-45_8 = star from celestial-body list. R2 †† AB not used C = 1 (earth LMK) C = 2 (moon LMK) DE not used R3 †† C = 1 (earth horizon) C = 2 (moon horizon) D = 1 (near horizon) D = 2 (far horizon)	•Accept new data •Upon crew's PRO– (1) proceed to next step if R2 ≠ 00 (landmark) (2) proceed to step 11 if R1 = 00 (planet) and R3 ≠ 00 (horizon) (3) proceed to step 12 if R1 = 01-45 (star code) and R3 ≠ 00 (horizon) (4) turn on OPR ERR if R1 ≠ 00-45 or if R2-R3 are illogically configured.	•Load (V25E) desired data. •Key PRO	†† Either R2 or R3 should be zero, but not both: R2 is zero for horizon measurement; R3 is zero for landmark measurement. NOTE.–steps 9-16 are bypassed if IMU is not on and aligned, i.e., if REFSMFLG is not set.
10		FL V06 N89††† (Star/planet-landmark)	P23	Display landmark data (Longitude is divided by two for scaling.) Legal values in R1 and R2 are 0-90 deg.	R1 ± xx.xxx deg LAT R2 ± xx.xxx deg LONG/2 R3 ± xxx.xx n.mi. ALT "+" is north latitude and east longitude. Altitude is above Fischer ellipsoid (earth) or mean lunar radius (MLR)	•Accept new data •Upon crew's PRO, proceed to next step if NOUN 70 (R1)–step 9–equals zero (planet); proceed to step 12 if NOUN 70 (R1) equals 01-45 (star code).	•Load (V25E) desired data •Key PRO	†††Occurs only if NOUN 70 (R2) not equal to zero (landmark).

TABLE 4.2.4-I.

CISLUNAR NAVIGATION PROGRAM (CMC P23)

DSKY PROCEDURES (SHEET 4 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
11	---	FL V06 N88# (Planet-land-mark/horizon)	P23	Display planet position vector at GET.	R1 +.xxxxx XPL R2 ∓.xxxxx YPL R3 ∓.xxxxx ZPL	•Accept new data •Upon crew's PRO, integrate CSM state vector to present time, calculate the attitude required to point the LLOS at the horizon or landmark, proceed to next step.	•Load (V25E) desired data •Key PRO	#Occurs only if NOUN 70 (R1) = 00 (planet)
12	---	FL V50 N25	P23	Request "Please perform three-axis automatic maneuver to tracking attitude."	R1 00202 R2 Blank R3 Blank	•Upon crew's PRO, calculate the desired gimbal angles for a three-axis maneuver. Set 3AXISFLG and proceed to next step. •Upon crew's ENTR, use VECPOINT to calculate desired gimbal angles, reset 3AXISFLG, and proceed to next step.	•To perform three-axis maneuver, key PRO. •To perform VECPOINT maneuver, key ENTR.	
13	---	FL V50 N18 (R60)	P23	Display desired final gimbal angles and request "Please perform automatic maneuver" to tracking attitude.	R1 + xxx.xx deg OGA R2 + xxx.xx deg IGA R3 + xxx.xx deg MGA	•Upon crew's PRO, proceed to next step. •Upon crew's ENTR, exit R60, set V94FLAG, and proceed to step 16. •Upon crew's V34E, do R00 and exit R60.	•To perform automatic maneuver— (1) set SC CONT to CMC (2) set CMC MODE to AUTO (3) key PRO •To perform maneuver manually, use RHC, referencing out the window or the FDAI Ball and attitude-error needles. •To load ground-computed angles (three-axis), key V25N22E, load data, then perform the maneuver.	NOTE.—If crew keyed PRO in response to FL V50 N25 (R1, 00202)—step 12—gimbal angles correspond to desired three-axis tracking attitude and present IMU orientation. NOTE.—Although a three-axis maneuver is desirable, it may produce gimbal lock (Alarm 00401). Should, upon a PRO response to FL V50 N25 (R1, 00202), an Alarm 00401 occur, clear the alarm and key ENTR to FLV50N18. If crew keyed ENTR in response to step 12, gimbal angles correspond to VECPOINT calculations—vehicle attitude about pointing vector unconstrained.

TABLE 4.2.4-I.
CISLUNAR NAVIGATION PROGRAM (CMC P23)
DSKY PROCEDURES (SHEET 5 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
14	---	V06 N18 (R60)	P23	Display desired final gimbal angles during automatic maneuver.	R1+xxx.xx deg OGA R2+xxx.xx deg IGA R3+xxx.xx deg MGA	•Perform maneuver. •When maneuver terminates or is interrupted, proceed to next step.	•Monitor •If maneuver approaches gimbal lock, use RHC to complete the maneuver manually—referencing out the window or FDAI Ball and attitude-error needles.	Maneuver rate will be that last prescribed by crew (R03). If MGA = ± 75 deg occurs, maneuver will terminate and enter ATT HOLD. Program proceeds to next step. Crew must use RHC to maneuver around gimbal lock.
15	---	FL V50 N18 (R60)	P23	Display desired final gimbal angles and request "Please perform auto maneuver."	R1+xxx.xx deg OGA R2+xxx.xx deg IGA R3+xxx.xx deg MGA	•Upon crew's PRO, recycle maneuver. •Upon crew's ENTR, exit R60, set V94FLAG, and proceed to next step. •Upon crew's V34E, do R00 and exit R60.	•To recycle maneuver, key PRO. •To proceed to step 16, key ENTR (present attitude and displayed gimbal angles agree within deadband limits).	---
16	---	V06 N92 (R52)	P23	Nonflashing display of desired shaft and trunnion angles.	R1+xxx.xx deg shaft R2+xx.xxx deg trunnion R3 blank	•Reset Sighting Mark Flag •Get present IMU orientation from storage (REFSMMAT). •Read present vehicle attitude from ICDUs. •Get star/landmark data from CMC storage •Compute target vector from CSM to star/landmark •Calculate the required optics angles to point the SLOS along the target vector •Display Alarm 00404 if target is not within optics cone of acquisition (COA). •If target within COA and the required trunnion angle is ≤ 49.775 deg, drive shaft and trunnion CDUs to acquire target; if required trunnion CDU is >49.775 deg, drive shaft CDU and drive trunnion CDU to 49.775 deg. •Upon crew's setting OPTICS MODE switch to MAN, proceed to next step and continue to recycle R52 until terminated by R53.	•Monitor •When target is acquired, set OPT MODE switch to MAN.	Possible Alarm FL V05 N09 R1, R2 or R3—00404 (target not within 90 deg COA). Either manually maneuver S/C to reduce required trunnion angle or terminate program (V34E). If manual maneuver is performed successfully, key PRO—two-second delay required after priority display. NOTE. —V94E can be used to terminate R52/R53 anytime before MARK acceptance. If crew keys V94E after a MARK but before accepting it, the MARK data will be lost.

TABLE 4.2.4-1.

CISLUNAR NAVIGATION PROGRAM (CMC P23)

DSKY PROCEDURES (SHEET 6 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
17	---	FL V51 (R53)	P23	Request "Please MARK."	R1 Blank R2 Blank R3 Blank	•Set Sighting Mark Flag, and set Mark Index = 1 •Upon crew's MARK, set MARKFLAG, store mark data, and decrement Mark Index by one. •Go to next step when Mark Index = 0.	To MARK— (1) Set OPT COUPLING to RSLV (2) Set OPT SPEED to LO (3) Use MIC to position substellar point near center of SXT FOV (Fig. 4.2.4-2). (4) Use OHC to superimpose star/planet on substellar point (Fig. 4.2.4-2). (5) MARK	Possible Alarm PROG Alarm 00110 (MARK REJ depressed when no MARK has been taken). Key RSET and proceed to take MARK if desired.
18	---	FL V50 N25 (R53)	P23	Request "Please Terminate mark sequence."	R1 00016 R2 Blank R3 Blank	•Upon crew's MARK REJ, erase last set of mark data and increment MARK counter by one. Reset Mark Flag and return to step 17.* •Upon crew's PRO, reset Mark Flag, set Terminate Flag, exit R53, reset V94FLAG, and proceed to next step. Upon crew's PRO, set SAVECFLG (indicating that a mark has been taken)	•To accept MARK data and proceed to next step, key PRO. •To reject MARK and return to FL V51, key MARK REJ.* •To terminate R52–R53 and return to step 12, key V94E. •To terminate R52–R53 and P23, key V34E or V37E xxE.	NOTE. —Should crew key V94E, V34E, or V37E xxE before accepting mark data (PRO to FL V50 N25, R1 = 00016), the data will be lost. *NOUN 25 (R1, 00016) remains.
19	---	FL V05 N71	P23	Display post-mark measurement identification.	R1 000DE (star) R2 ABCDE (LMK) R3 00CD0 (HOR) R1 DE = star ID 00_8 = any planet 01_8–45_8 = star from celestial-body list R2## AB not used C = 1 (earth LMK) C = 2 (moon LMK) DE not used R3## C = 1 (earth horizon) C = 2 (moon horizon) D = 1 (near horizon) D = 2 (far horizon)	•Accept data •Upon crew's PRO— (1) If R2 ≠ 00 (landmark), proceed to next step. (2) If R1 = 00 (planet), and and R3 ≠ 00 (horizon), proceed to step 21. (3) If R1 = 01–45 (star-code), and R3 ≠ 00 (horizon), proceed to step 22. (4) Turn on OPR ERR if R1 ≠ 00–45 or if R2–R3 are illogically configured.	IMU on and aligned (REFSMFLG set) •Verify data •Key PRO IMU not on or not aligned (REFSMFLG reset) •Load data (V25E) for measurement performed. •Key PRO	##Either R2 or R3 should be zero, but not both: R2 is zero for horizon measurement; R3 is zero for landmark measurement. NOTE. —NOUN 71 contains values originally loaded into NOUN 70—step 9 (REFSMFLG set). If step 9 was bypassed (REFSMFLG reset), the appropriate data for the measurement performed in step 17 must now be loaded.

TABLE 4.2.4-I.
CISLUNAR NAVIGATION PROGRAM (CMC P23)
DSKY PROCEDURES (SHEET 7 OF 7)

No.	Entry Point	Display	PROG	Purpose	Registers	CMC Operation	Crew Action	Remarks
20	---	FL V06 N89### (star/planet-landmark)	P23	Display landmark data (Longitude is divided by two for scaling. Legal values in R1 and R2 are 0-90 deg).	R1 ± xx.xxx deg LAT R2 ± xx.xxx LONG/2 R3 ± xxx.xx n.mi. ALT "+" is north latitude and east longitude. Altitude is above Fischer ellipsoid (earth) or MLR (moon).	•Accept data •Upon crew's PRO, proceed to next step if NOUN 71 (R1)-step 19-equals zero (planet); proceed to step 22 if NOUN 71 (R1) equals 01-45 (star code).	IMU on and aligned (REFSMFLG set) •Verify data •Key PRO IMU not on or not aligned (REFSMFLG reset) •Load data (V25E) for measurement performed. •Key PRO.	###Occurs only if NOUN 71 (R2) not equal to zero (landmark)
21	---	FL V06 N88*# (Planet-landmark/horizon)	P23	Display planet position vector at MARK GET.	R1 ± .xxxxx XPL R2 ± .xxxxx YPL R3 ± .xxxxx ZPL	•Accept data •Upon crew's PRO, proceed to next step.	IMU on and aligned (REFSMFLG set) •Verify data •Key PRO IMU not on and aligned •Load data (V25E) for measurement performed. •Key PRO	*#Occurs only if NOUN 71 (R1) equals zero (planet).
22	---	FL V06 N49	P23	Display state vector changes.	R1 + xxx.xx n.mi. ΔR R2 + xxxx.x ft/sec Δv R3 Blank ΔR is magnitude of position-vector change. Δv is magnitude of velocity-vector change.	•Compute and display state-vector change due to measurement. •Upon crew's V32E, do R00. •Upon crew's PRO, update CMC state vector, and do R00.	•To accept update, key PRO. •To reject update, key V32E.	---
23	---	FL V37 (R00)	P23	Request "Please select new program."	---	---	•To reselect P23, key 23E. •To select Pxx, key xxE.	---

4.2.4.2 Procedures

Table 4.2.4-I is a summary of P23 DSKY procedures. An amplified description is presented here.

1. After preliminary procedures have been performed as prescribed by the appropriate mission documentation, initiate the Cislunar Navigation Program (P23) by keying VERB 37 ENTR 23 ENTR. Observe flashing display of Checklist code requesting "Please perform celestial-body acquisition:"

   FL VERB 50 NOUN 25 (R57)

R1	00015	Checklist Code
R2	Blank	
R3	Blank	

   NOTE.—FL VERB 50 NOUN 25 does not occur if the IMU is not on and aligned. If IMU is not on and aligned (REFSMFLG reset), P23 begins at step 7 and omits steps 9–16.

   If a CMC maneuver to point the LLOS at the selected star is desired, key PRO.

   NOTE.—If no maneuver is desired, key ENTR and proceed to step 7; if a manual maneuver is desired, key ENTR, manually maneuver the spacecraft to acquire a suitable star in the SXT FOV, and proceed to step 7. (See, however, paragraph 4.2.4.1.)

2. Observe flashing display of the octal code designating the celestial body to be used in calibrating the optics (not preloaded):

   FL VERB 01 NOUN 70 (R57)

R1	000xx	Code
R2	Blank	
R3	Blank	

where xx is—

00_8 = any planet
$01_8 - 45_8$ = star from celestial-body list
46_8 = sun
47_8 = earth
50_8 = moon

NOTE.—FL VERB 01 NOUN 70 does not occur if crew keys ENTR in response to FL VERB 50 NOUN 25 (step 1). Instead, P23 proceeds to step 7.

. Load (VERB 21 ENTR) desired code into Register R1. (See paragraphs 4.2.1.1 and 4.2.1.2.)
. PRO

NOTE.—If NOUN 70 (R1) contains xx = 00_8, program proceeds to step 3; otherwise, program proceeds to step 4.

Planet Option

3. Observe flashing display of planet position vector at GET (not preloaded):

FL VERB 06 NOUN 88 (R57)

R1	±.xxxxx	XPL
R2	±.xxxxx	YPL
R3	±.xxxxx	ZPL

where XPL, YPL, and ZPL are the x, y, and z components of the planet's position vector at time of measurement. (See paragraph 4.2.4.1.2.)

. Obtain from tables and load (VERB 25 ENTR) x, y, z components of calibration planet.
. PRO

4. Observe flashing display of desired final gimbal angles and request "Please perform automatic maneuver" to calibration tracking attitude:

FL VERB 50 NOUN 18 (R60)

R1	+xxx.xx	deg	OGA
R2	+xxx.xx	deg	IGA
R3	+xxx.xx	deg	MGA

NOTE.—Vehicle attitude for pointing optics shaft axis along LLOS is calculated using VECPOINT (attitude about LLOS unconstrained).

- To perform automatic maneuver—

1) set SC CONT switch to CMC
2) set CMC MODE switch to AUTO
3) key PRO

NOTE.—If the crew elects to perform the maneuver manually, he uses the RHC, referencing out the window or the FDAI Ball and attitude error needles (MODE II). Upon the crew's ENTR, the program proceeds to step 7.

Automatic Maneuver (PRO to FL VERB 50 NOUN 18)

5. Observe nonflashing display of final gimbal angles during automatic maneuver:

VERB 06 NOUN 18 (R60)

R1	+xxx.xx	deg	OGA
R2	+xxx.xx	deg	IGA
R3	+xxx.xx	deg	MGA

NOTE.—Maneuver rate will be that last prescribed by the crew (R03). If MGA = ±75 deg occurs, maneuver terminates and returns FL VERB 50 NOUN 18 (step 6).

- Monitor
- If maneuver approaches gimbal lock or terminates, use RHC to complete maneuver manually, avoiding gimbal lock and referencing out the window or the FDAI Ball and attitude error needles (MODE II).

6. When maneuver terminates or is interrupted, observe return of flashing display and request to perform attitude maneuver:

FL VERB 50 NOUN 18 (R60)

R1	+xxx.xx	deg	OGA
R2	+xxx.xx	deg	IGA
R3	+xxx.xx	deg	MGA

- To recycle (trim) the maneuver, key PRO and repeat steps 5 and 6.
- When present attitude and displayed gimbal angles agree within deadband limits, key ENTR.

7. Observe flashing display, "Please perform calibration mark."

FL VERB 59 (R57)

R1	Blank
R2	Blank
R3	Blank

NOTE.—When the IMU is not on and aligned, step 7 is the first display in P23. Step 7 is the second P23 display if crew elects in step 1 to bypass the attitude maneuver or to perform the maneuver manually (ENTR response to step 1).

- To perform optics-calibration check—
  1) set OPT ZERO switch to OFF
  2) set OPT SPEED switch to LO
  3) set OPT MODE switch to MAN
  4) set OPT TEL TRUN to SLAVE to SXT
  5) set OPTICS COUPLING to DIR
  6) use minimum-impulse controller (MIC) to center calibration feature in SXT
  7) use optics hand controller (OHC) to superimpose SLOS on LLOS
  8) depress MARK button

NOTE.—To obtain best results, 10-arc-sec precision is necessary when the navigation measurement is taken (in step 17). Thermal gradients, however, can cause trunnion biases as large as 10–30 arc-sec. To achieve thermal equilibrium of heat sources within the optical subsystem (OSS), the crew should allow 30 minutes after optics turn on before performing calibration. The measured trunnion bias will then be stored for subsequent use in navigation measurements. Unless the optics are turned off or are pointed within 15 deg of the sun, subsequent recalibration should not be necessary. (Recalibration is recommended, however, after each 30-minute period of P23 activity.)

. To bypass the optics-calibration check—

1) set OPTICS MODE switch to CMC (if IMU on and aligned) or to MAN (if IMU not on and aligned).

2) key ENTR. If IMU is on and aligned, program proceeds to step 9. If IMU is not on and aligned, program proceeds to step 17.

Optics Calibration Performed

8. Observe flashing display of trunnion bias angle:

FL VERB 06 NOUN 87 (R57)

R1	Blank	
R2	+xx.xxx	deg
R3	Blank	

. To accept mark, key PRO

NOTE 1.—If REFSMFLG set, program proceeds to next step. If REFSMFLG reset, program proceeds to step 17.

NOTE 2.—Small negative trunnion angles can occur. Such angles are displayed as the sum of the negative value and +90 deg; e.g., an angle of -0.1 deg is displayed as 89.900 deg in NOUN 87.

. To reject MARK, resight as in step 7 and MARK again

. To reject MARK and return to step 1 (REFSMFLG set), key VERB 32 ENTR.

. To load crew-recorded value, key VERB 22 NOUN 94 ENTR, load R2, and then key PRO.

9. Observe flashing display of pre-mark measurement identification (not preloaded):

NOTE.—Steps 9–16 are bypassed if IMU is not on and aligned, i.e., if REFSMFLG is not set.

FL VERB 05 NOUN 70

R1 000DE (star identification)
R2 ABCDE (landmark identification)
R3 00CD0 (horizon identification)

where in—

R1

DE = star identification
00_8 = any planet
$01_8 - 45_8$ = star from celestial-body list

R2

AB not used
C = 1 (earth landmark)
C = 2 (moon landmark)
DE not used

R3

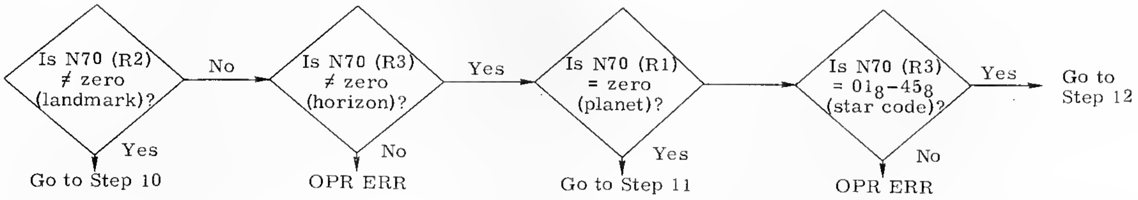
C = 1 (earth horizon)
C = 2 (moon horizon)
D = 1 (near horizon)
D = 2 (far horizon)

NOTE.—Either R2 or R3 should be zero, but not both: R2 is zero for horizon measurements; R3 is zero for landmark measurements.

. Load (VERB 25 ENTR) identification data (see paragraphs 4.2.4.1.1, 4.2.4.1.2).

. PRO

NOTE.—



STAR/PLANET-LANDMARK (NOUN 70, C of R2 $\neq 0_8$)

10. Observe flashing display of landmark data (not preloaded):

FL VERB 06 NOUN 89

R1	±xx.xxx	deg	LAT
R2	±xx.xxx	deg	LONG/2
R3	±xxx.xx	n.mi.	ALT

where (in R1, R2) "+" denotes north latitude and east longitude, and where (in R3) altitude is relative to the Fischer ellipsoid (earth) or the mean lunar radius (MLR).

NOTE.—Longitude (in R2) is divided by two for scaling. Legal values in R1 and R2 are 0–90 deg.

. Load (VERB 25 ENTR) coordinates and altitude of designated landmark

. PRO

NOTE.—If NOUN 70 (R1)—step 9—contains zero (planet option selected), program proceeds to next step. If NOUN 70 (R1) contains 01_8–45_8, program proceeds to step 12.

PLANET-LANDMARK/HORIZON (NOUN 70, DE of R1 = 00_8)

11. Observe flashing display of planet position vector at GET:

FL VERB 06 NOUN 88

R1	±.xxxxx	XPL
R2	±.xxxxx	YPL
R3	±.xxxxx	ZPL

where XPL, YPL, and ZPL are the x, y, and z components of the planet's position vector at time of measurement. (See paragraph 4.2.4.1.2.)

. Obtain from tables and load (VERB 25 ENTR) x, y, z components of planet designated for navigation measurement

. PRO

12. Observe flashing display, "Please perform three-axis automatic maneuver" to tracking attitude:

FL VERB 50 NOUN 25

R1	00202	Checklist Code
R2	Blank	
R3	Blank	

NOTE.—Unless a three-axis maneuver would result in a final-attitude MGA of ±60 deg—signaled by the occurrence of a 00401 alarm after a PRO response to flashing VERB 50 NOUN 25—the preferred response to flashing VERB 50 NOUN 25 is PRO, which gives a three-axis maneuver. The advantage of a three-axis maneuver is that the spacecraft will be oriented such that a line drawn between the selected star and the center of the reference planet will lie in the spacecraft X,Z plane. Then, with the optics shaft axis at 180 deg, crew adjustments to align the reticle with the substellar tangent (Figure 4.2.4-2) can be accomplished by pure yaw maneuvers. The 180-deg shaft-angle orientation also prevents LM occultation of the SLOS.

. To perform three-axis maneuver, key PRO.

13. Observe flashing display of desired final gimbal angles and request "Please perform automatic maneuver" to tracking attitude.

FL VERB 50 NOUN 18 (R60)

R1	+xxx.xx	deg	OGA
R2	+xxx.xx	deg	IGA
R3	+xxx.xx	deg	MGA

NOTE.—If crew keyed PRO in response to FL VERB 50 NOUN 25 (R1, 00202)—step 12—gimbal angles correspond to desired three-axis tracking attitude and present IMU orientation. If crew keyed ENTR in response to step 12, gimbal angles correspond to VECPOINT calculations—vehicle attitude about pointing vector unconstrained.

- To change angles (three-axis) to ground supplied values, key VERB 25 NOUN 22 ENTR and load angles
- To perform automatic maneuver—
  1) set SC CONT switch to CMC
  2) set CMC MODE switch to AUTO
  3) PRO

  NOTE.—If the crew elects to perform the maneuver manually, he uses the RHC, referencing out the window or the FDAI Ball and attitude error needles (MODE II). Upon the crew's ENTR, the program proceeds to step 16.

AUTOMATIC MANEUVER (PRO to FL VERB 50 NOUN 18)

14. Observe nonflashing display of final gimbal angles during automatic maneuver:

VERB 06 NOUN 18 (R60)

R1	xxx.xx	deg	OGA
R2	xxx.xx	deg	IGA
R3	xxx.xx	deg	MGA

NOTE.—Maneuver rate will be that last prescribed by the crew (R03). If MGA = ±75 deg occurs, maneuver terminates and returns to FL VERB 50 NOUN 18 (step 15).

- Monitor
- If maneuver approaches gimbal lock or terminates, use RHC to complete maneuver manually, avoiding gimbal lock and referencing out the window or the FDAI Ball and attitude error needles (MODE II).

15. When maneuver terminates or is interrupted, observe return of flashing display of desired final gimbal angles and request to perform attitude maneuver:

    FL VERB 50 NOUN 18 (R60)

R1	+xxx.xx	deg	(OGA)
R2	+xxx.xx	deg	(IGA)
R3	+xxx.xx	deg	(MGA)

    - To recycle (trim) the maneuver, key PRO and repeat steps 14 and 15
    - When present attitude and displayed gimbal angles agree within deadband limits, key ENTR

16. Observe nonflashing display of desired optics angles:

    VERB 06 NOUN 92 (R52)

R1	+xxx.xx	deg	Shaft
R2	+xx.xxx	deg	Trunnion
R3	Blank		

Possible ALARM

FL VERB 05 NOUN 09

R1, R2, or R3—00404 (target not within 90-deg cone). Either manually maneuver spacecraft to reduce required trunnion angle or terminate program (VERB 34 ENTR). If manual maneuver is performed successfully, key PRO—two-second delay required after this and any priority display.

PROG Alarm (key VERB 5 NOUN 9 ENTR to get display of alarm code)

R1, R2, or R3—00120 (optics torquing requested when optics have not been zeroed since last FRESH START or RESTART). Set OPTICS ZERO switch to OFF, then to ZERO. Key RSET and allow ~15 sec for zeroing.

PROG Alarm (key VERB 5 NOUN 9 ENTR to get display of alarm code)

R1, R2, or R3—00116 (OPTICS ZERO set from ZERO to OFF before the 15-sec zeroing time had elapsed). Return OPTICS ZERO switch to ZERO and wait 15 sec for zeroing.

- Monitor target acquisition
- When target is acquired, set OPTICS MODE switch to MAN

NOTE.—VERB 94 ENTR can be used to terminate R52/R53 anytime before MARK acceptance. If crew keys VERB 94 ENTR after a MARK but before accepting it, the MARK data will be lost, and the program returns to Step 12.

17. Observe flashing display, "Please MARK":

FL VERB 51 (R53)

R1 Blank
R2 Blank
R3 Blank

- To MARK—
  1) set OPT COUPLING switch to RSLV
  2) set OPT SPEED switch to LO
  3) use minimum impulse controller (MIC) to position substellar point near center of SXT FOV (Figure 4.2.4-2)
  4) use OHC to superimpose star/planet on substellar point (Figure 4.2.4-2)
  5) MARK

Possible ALARM PROG Alarm 00110 (MARK REJ depressed when no mark has been taken). Key RSET and proceed to MARK if desired.

18. Observe flashing display, "Please terminate MARK sequence":

FL VERB 50 NOUN 25 (R53)

R1 00016 Checklist Code
R2 Blank
R3 Blank

- To accept MARK data, key PRO
- To reject MARK and return to FL VERB 51 NOUN 25 (R1, 00016), key MARK REJ. Crew response is as in Step 17.
- To terminate and return to step 12, key VERB 94 ENTR

NOTE.—If VERB 94 ENTR is keyed before crew keys PRO in response to FL VERB 50 NOUN 25 (R1, 00016), MARK data will be lost.

- To terminate R52–R53 and P23, key VERB 34 ENTR or VERB 37 ENTR xx ENTR

NOTE.—If P23 is terminated before crew keys PRO in response to FL VERB 50 NOUN 25 (R1, 00016), MARK data will be lost.

19. Observe flashing display of post-mark measurement identification:

FL VERB 05 NOUN 71

R1 000DE (star identification)
R2 ABCDE (landmark identification)
R3 00CD0 (horizon identification)

where in—

<u>R1</u>

DE = star identification

00_8 = any planet

01_8-45_8 = star from celestial-body list

<u>R2</u>

AB not used

C = 1 (earth landmark)

C = 2 (moon landmark)

DE not used

<u>R3</u>

C = 1 (earth horizon)

C = 2 (moon horizon)

D = 1 (near horizon)

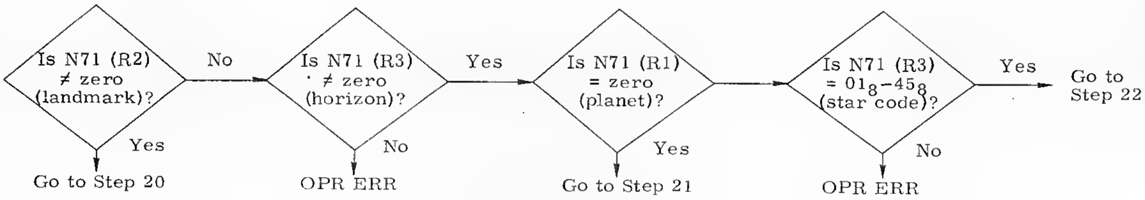
D = 2 (far horizon)

<u>NOTE 1</u>.—If step 9 was bypassed (REFSMFLG reset), the appropriate data for the measurement performed in step 17 must now be loaded. If step 9 was not bypassed (REFSMFLG set), NOUN 71 contains values originally loaded into NOUN 70, and should not be changed unless MARK was taken on a target and substellar reference other than as originally specified.

- To accept data, key PRO
- To load new data (MARK taken on target and substellar reference not specified in step 9), key VERB 25 ENTR, load data, and key PRO

<u>NOTE 2</u>.—Either R2 or R3 should be zero, but not both: R2 is zero for horizon measurements; R3 is zero for landmark measurements.

<u>NOTE 3</u>.—



STAR/PLANET-LANDMARK (NOUN 71, C of R2 $\neq 0_8$)

20. Observe flashing display of landmark data:

FL VERB 06 NOUN 89

R1	±xx.xxx	deg	LAT
R2	±xx.xxx	deg	LONG/2
R3	±xxx.xx	n.mi.	ALT

where (in R1 and R2), "+" denotes north latitude and east longitude, and where (in R3) altitude is relative to the Fischer ellipsoid (earth) or the mean lunar radius (MLR).

NOTE.—Longitude (in R2) is divided by two for scaling. Legal values in R1 and R2 are 0–90 deg.

- To accept data (see NOTE 1 in step 19), key PRO
- To load data for measurement performed (see NOTE 1 in step 19), key VERB 25 ENTR, load latitude, longitude/2, and altitude of landmark, and key PRO

NOTE.—If NOUN 71 (R1)—step 19—contains zero (planet option selected), program proceeds to next step. If NOUN 71 (R1) contains 01_8–45_8, program proceeds to step 22.

PLANET-LANDMARK/HORIZON (NOUN 71, DE of R1 = 00_8)

21. Observe flashing display of planet position vector at MARK GET:

FL VERB 06 NOUN 88

R1	±.xxxxx	XPL
R2	±.xxxxx	YPL
R3	±.xxxxx	ZPL

where XPL, YPL, and ZPL are the x, y, and z components of the planet's position vector at time of measurement. (See paragraph 4.2.4.1.2.)

- To accept data (see NOTE 1 in step 19), key PRO
- To load data for measurement performed (see NOTE 1 in step 19), key VERB 25 ENTR, obtain from tables and load x, y, z components of measurement planet, and key PRO.

22. Observe flashing display of state vector changes resulting from measurement:

    FL VERB 06 NOUN 49

R1	+xxx.xx	n.mi. ΔR
R2	+xxxx.x	ft/sec Δv
R3	Blank	

    where ΔR is magnitude of position-vector change, and Δv is magnitude of velocity-vector change.

    - To accept update, key PRO
    - To reject update, key VERB 32 ENTR

    NOTE.—If ΔR or Δv is greater than 50 n.mi./50 ft/sec, reject the update and reinitiate P23 for another measurement—ensuring correct star and technique. If the second update is similar to the first, accept it unless the magnitude is such as to suggest a bad SXT. Consult Checklist contingency procedures. Nominal behavior is for first update to meet 50 n.mi./50 ft/sec criterion and for subsequent updates to converge toward zero. (See paragraphs 4.2.4.3—4.2.4.7 below.)

23. Observe flashing display, "Please select new program":

    FL VERB 37 (R00)

    - To reselect P23, key 23 ENTR
    - To select Pxx, key XX ENTR

    NOTE.—Nominal procedures call for three MARKS to be taken on one star, followed by a 10-minute interval before three MARKS on a second star, another 10-minute interval, and so on. Recalibration for trunnion bias should be performed every half hour during navigation or anytime that the optics have passed within 15 deg of the sun or have been turned off between measurements. (See paragraph 4.2.4.8 for typical tracking schedule.)

4.2.4.3 Influence of Measurement Geometry on State Vector

Figures 4.2.4-1a and b show the locus of spacecraft position determined by a single star-horizon measurement to be a cone of revolution about the horizon line of sight, with its apex angle (2θ) twice the angle formed by the star LOS and the horizon LOS. The onboard measurement technique used is not deterministic as the illustration implies, but employs a statistical-filtering technique to produce an optimum linear combination of weighted increments from each angle measurement. Each star-horizon angle measurement provides position information primarily in the plane of the measurement and orthogonal to the horizon LOS. A geometry vector $\underline{b}$ (Figures 4.2.4-1a and b) associated with each star-angle measurement characterizes its information content. The statistical uncertainty of vehicle position is reduced primarily along a dimension parallel to the $\underline{b}$ vector for each measurement star. Therefore, angle measurements should be made on stars located in different measurement planes. Stars with a large $\underline{b}$-vector component in the orbital plane are preferred, however.

A sequence of P23 angle measurements processed through the W-matrix to produce statistically optimum weighted updates to the onboard state vector differs fundamentally from a simultaneous three-dimensional fix on three well-separated (ideally orthogonal) stars. P23-derived position information efficiently minimizes state-vector uncertainties in a plane orthogonal to the horizon LOS, but is somewhat less effective in reducing range and range-rate uncertainty along the LOS. The dominant consideration in providing position and velocity inputs to P37 is minimizing uncertainty in the radial miss-distance in the orbital plane of the ±20-n.mi. reentry window. The effect of this on P23 procedure is to dictate that, whenever possible, star measurements be made on stars whose measurement planes are near the orbital plane.

4.2.4.4 Post-measurement Evaluation

Figure 4.2.4-3 shows the change in perigee that resulted from a group of 15 sightings made on the lunar horizon at a distance of 45,000 n. mi. during the translunar leg of APOLLO 8. At the end of this group of measurements, the indicated perilune was 67 n. mi., about 1.8 n. mi. less than the value later reconstructed from MSFN groundtrack data. Perigees computed onboard using either P37 or R30 (obtainable with VERB 82) should converge in the manner shown during a sequence of P23 star-horizon measurements, whether earth- or moon-centered.

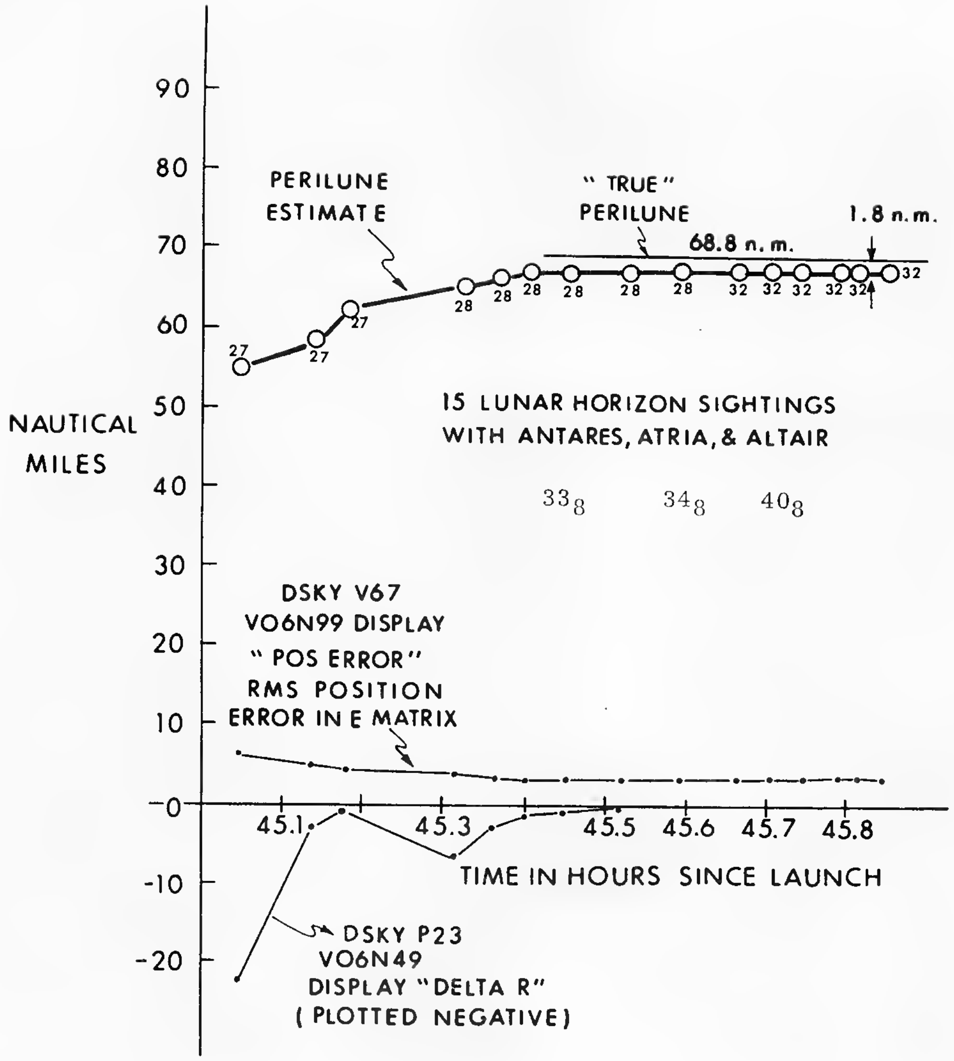


Figure 4.2.4-3. Typical Results of P23 Midcourse Navigation (APOLLO 8, Translunar)

4.2.4.5 Effects of Calibration and Substellar Pointing-angle Errors

Calibration of sextant trunnion-angle bias at regular (approximately 30-minute) intervals is recommended to compensate for thermal (internal and external) effects. For example, an uncalibrated 20-arc-second bias corresponds to about a 10-n.mi. position error estimate at 100,000-n.mi. range.

Another source of trunnion error results from sightings not taken precisely on the substellar point. Table 4.2.4-II indicates how measured horizon altitude is biased by errors in the pointing angle (see Figure 4.2.4-6) as a function of range from the earth. Lunar horizon-bias error is roughly four times as great for comparable pointing-angle error.

TABLE 4. 2. 4-II

HORIZON ALTITUDE BIAS ERROR AS A FUNCTION OF RANGE AND POINTING ERROR: EARTH HORIZON*

Substellar Pointing Error (θ_{PE}), arc minutes	Range, n.mi.		
	100, 000	150, 000	200,000
5	3 n.mi.	7	12-1/2
10	14	28	49-1/2
15	30	65	$\gtrsim$ 110

*Lunar horizon bias is approximately four times greater for comparable ranges and substellar pointing errors.

Substellar pointing angle errors are introduced when relatively near the reference body (< ~50,000 n.mi., for earth) by the perceptual limit due to apparent flatness of horizon when seen through the 28-power sextant. Around this range, use of the reticle pattern and trunnion-only drive motion are the navigator's primary aids. At greater ranges (~200,000 n.mi., for earth case), the dynamics of the vehicle limit the substellar pointing accuracy; therefore, minimizing CSM residual rates is most important. Trunnion calibration to within one-bit granularity (10 arc seconds) and pointing errors within 5 arc minutes (for ranges >60,000 n.mi.) and on the order of 10–12 arc minutes (for ranges <60,000 n.mi.) is well within crew capabilities and should result in adequate navigation performance.

4.2.4.6 Marking on the Horizon

Two factors must be considered in aligning the measurement plane. The first is determining the substellar point on the horizon. The cue for making this determination is the reticle pattern. The star image should be moved to the point on the horizon where a line tangent to that point is parallel to the horizontal axis of the reticle pattern. Figure 4.2.4-2 illustrates this alignment. The second is orienting the spacecraft so the star image and substellar point fall in the center two-thirds of the field of view. Judging the parallelism of the reticle to the tangent at the substellar point correctly is the most critical alignment operation. If the substellar point is found to lie near the side of the field of view, the spacecraft should be maneuvered to move this point near the center. The vertical location of the field of view is not critical.

To define the location of the earth's horizon, the center of the star image should be placed on the upper threshold of the atmosphere. The center, not the edge, of the star image should be used since focus and star magnitude affect the size of the image. The upper threshold of the earth's atmosphere does not appear as a sharp boundary.

Considerable variation exists in where different people perceive the threshold to be; each person, however, can accurately repeat his original selection. For this reason, APOLLO flight plans call for a series of marks to be made as close to the earth as possible to determine the horizon altitude that the navigator on each mission prefers to use.

4.2.4.7 W-Matrix

Current policy is to initialize the W-matrix only once, at the beginning of P23 takeover, to a large diagonal value provided in a contingency table. (See Table 4.2.4-III.) The large W-matrix initialization for the first transearth navigation measurements (30,000 feet and 30 fps) allows for the possibility of errors in the TEI burn. The large W-matrix does not adversely affect nominal performance, but it will enable a state vector with large errors to converge where a small one might not. Table 4.2.4-III gives W-initialization values for the APOLLO 11 mission. The growth of the W-matrix with extrapolation over the intervals between measurements is expected to provide adequate gain for subsequent P23 measurements. Since the size of the W increases exponentially with time, the size of the first ΔR, Δv in a sequence of P23 measurements will vary predictably with time. A good check on W growth before P23 measurement activity can be had using the W-matrix

position component display, VERB 67 ENTR. Knowing the size of the W to be nominal before marktaking is assurance that marks taken will in fact have the desired effect on the state vector.

TABLE 4.2.4-III

TYPICAL P23 CONTINGENCY TABLE FOR
W-MATRIX REINITIALIZATION VALUES

Communication Loss Time (hr from TEI)	W-Matrix To Be Input at 1st Mark	Batches of Data To Be Taken
0 - 1.5	30,000/30	All
1.5 - 10	73,000/5.0	2nd through end of schedule
10 - 35	30,000/0.5	1st beginning after loss through end of schedule
35 - Entry*	None	None

* This assumes a MSFN update at TEI +35 hours.

4.2.4.8 Typical Tracking Schedule (APOLLO 11)

Figure 4.2.4-4 shows the schedule of APOLLO 11 P23 activity plotted on a diagram of the translunar and transearth trajectories. Fifteen state vector updates were scheduled in all—two early in translunar coast and thirteen at intervals throughout the transearth return. Three marks were specified on each of three to five stars for each update, each mark requiring an individual P23 entry. Cislunar navigation during APOLLO 11 transearth coast produced 177 marks on 59 stars. (Notice that one star in each sequence was usually marked on twice.) The figure gives (1) the nominal time of each sequence of P23 activity, (2) the star code of each three-mark star-horizon measurement in the sequence, (3) three initials (e.g., NEH, FEH, signifying near-earth horizon and far-earth horizon respectively; NMH, FMH, signifying near-moon horizon and far-moon horizon), and (4) the times of the three midcourse corrections that would have been computed onboard using P37 had communications failed.

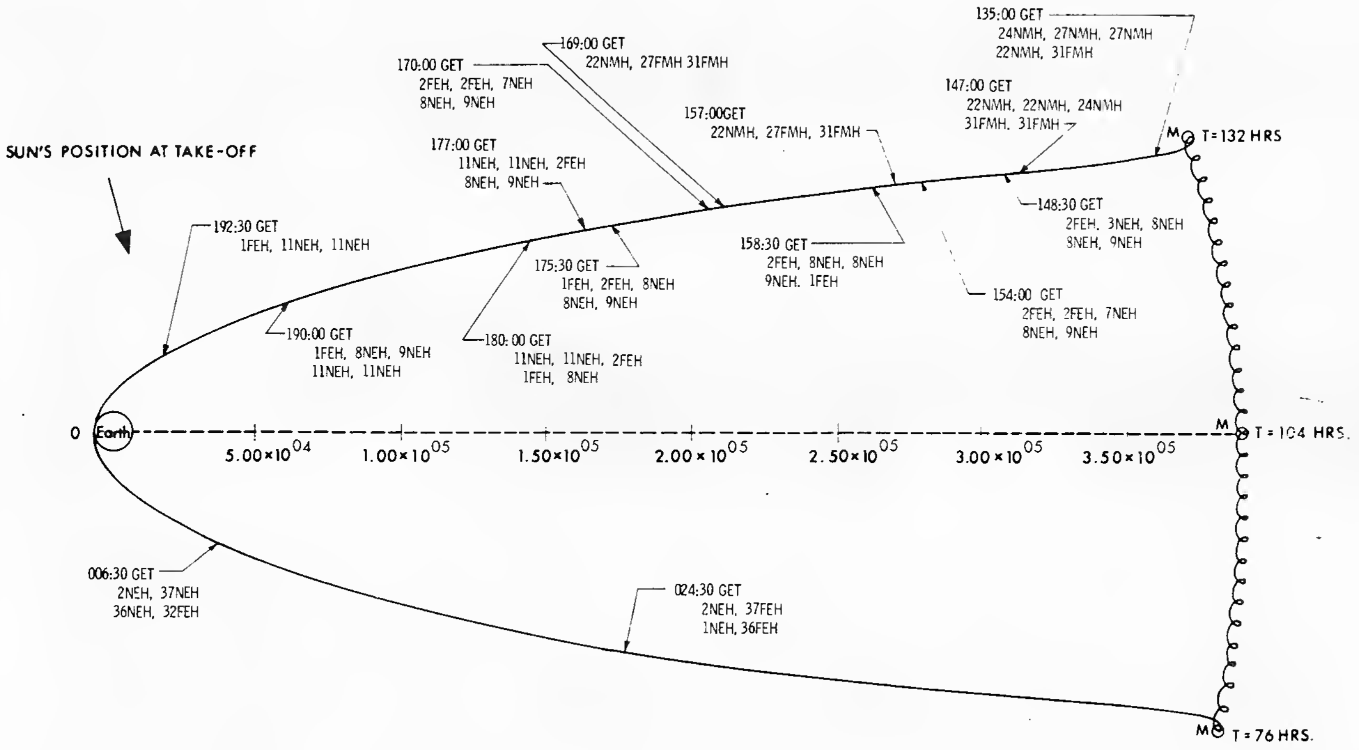


Figure 4.2.4-4. Typical P23 Activity for Translunar and Transearth Trajectories (APOLLO 11)

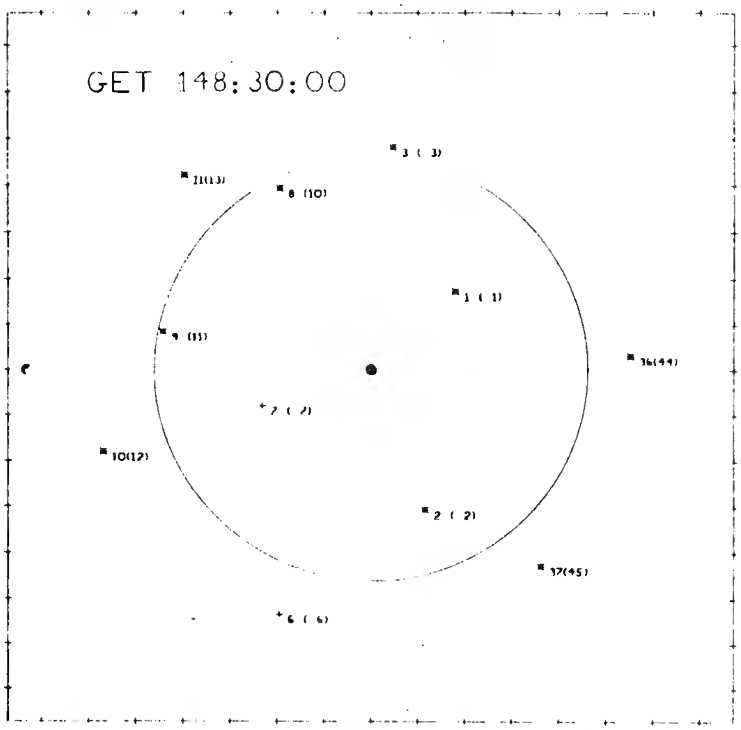


Figure 4.2.4-5a.

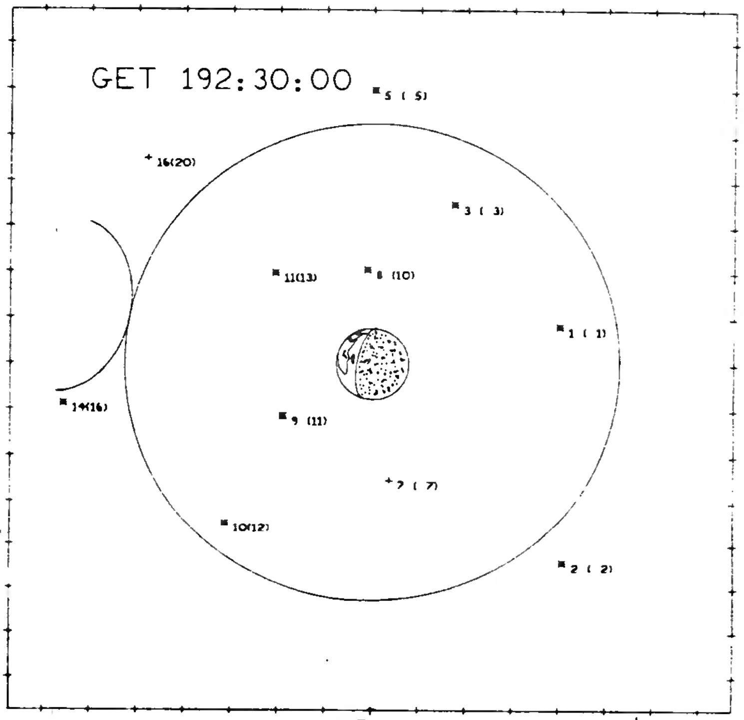


Figure 4.2.4-5b.

Figure 4.2.4-5. Available Measurement Stars Visible in SCT FOV at 148:30 GET and 192:30 GET during APOLLO 11

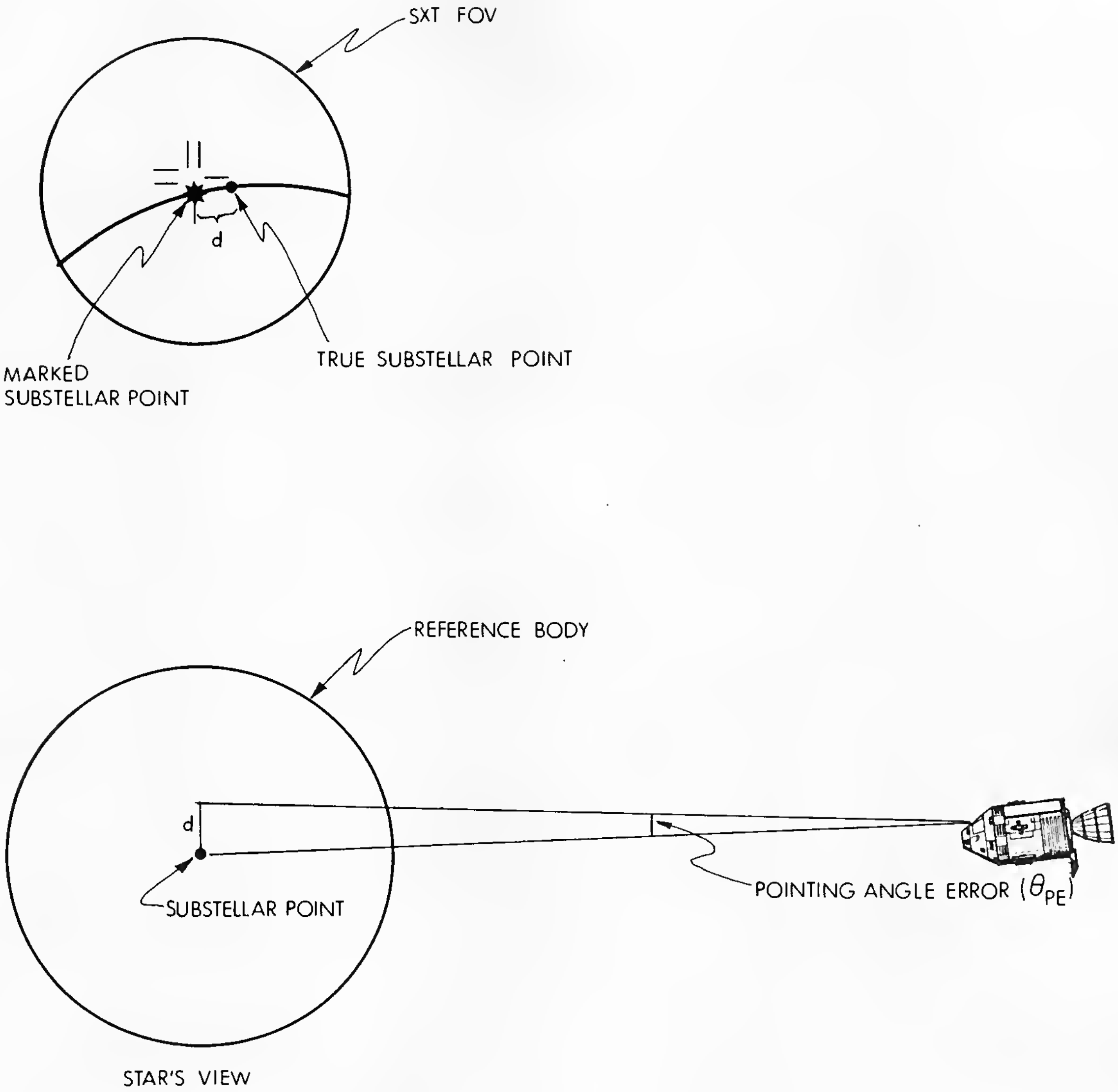


Figure 4.2.4-6. Substellar Pointing Error

The two sequences of P23 activity at 06:30 GET and 24:30 GET during the translunar phase are, in effect, rehearsals that obtain data on the consistency of the navigator's subjective perception of the earth horizon (i.e., its variance and any bias as a function of range) and star visibility thresholds. These preliminary translunar P23 data are analyzed from the downlink to refine the a priori statistical variance, which is subsequently stored in the CMC via uplink for use during the transearth cislunar-navigation phase.

Figures 4.2.4-5a and b show two views of earth that illustrate the available measurement stars visible in the 60-deg FOV of the SCT at the respective 148:30 GET and 192:30 GET P23 sequences of Figure 4.2.4-4. The 148:30 GET measurement sequence was the first (maximum range) measurement made during the transearth return after leaving the lunar sphere; the 192:30 GET sequence was the last navigation before reentry.

Notice that in the two sets of measurement stars in Figures 4.2.4-5a and b (corresponding to No. 9 at 148:30 and No. 11 at 192:30 in Figure 4.2.4-4), the last star marked on is nearest the (horizontal) orbital plane, consistent with the discussion in paragraph 4.2.4.3. Note also that the measurement schedule for each sequence of P23 activity on the mission flight plan is designed to minimize RCS fuel consumed by vehicle maneuvers necessary to orient the LLOS toward the substellar points of the successive measurement stars in each sequence.

4.2.4.9 Restarts

P23 is restart protected. Should a restart occur after a mark has been taken/accepted, the measurement data will be saved.

BLANK

4.2.5 P27, CMC Update

The CMC Update Program, P27, is used to insert update data into the CMC by digital uplink or by DSKY entry. P27 is entered via one of four extended verbs uplinked by the ground or keyed in by the crew; each verb designates a different type of input:

a. VERB 70 ENTR—provides ground capability to update the liftoff time.
b. VERB 71 ENTR—provides ground capability to update from 1 to 18 consecutive erasable memory locations whose address is specified as part of the input.
c. VERB 72 ENTR—provides ground capability to update from 1 to 9 individually specified erasable locations, which are not necessarily consecutive.
d. VERB 73 ENTR—provides ground capability to increment or decrement the CMC clock only.

Any ground command sequence normally transmitted via the uplink can be done by the crew instead via the DSKY. It is possible (though it is unlikely) for the ground to transmit input data by voice communications and for the crew to key in the update (manual-input option). A more likely use of the crew manual-input option is for correction of uplinked data. Tables 4.2.5-I and -II show the P27 DSKY displays and extended verbs, respectively.

4.2.5.1 Extended Verbs

The four extended verbs used for entry to P27 are functionally different. The verbs and the procedures associated with each are explained below.

4.2.5.1.1 VERB 70 ENTR.—VERB 70 allows the ground or crew to update the time of liftoff. The crew loads the time as xxxxx ENTR xxxxx ENTR, i.e., two pieces of data appear successively in R1 of the DSKY. After ENTR has been keyed—to give the crew an opportunity to correct the data—P27 displays a flashing VERB 21 NOUN 02 with the following registers:

R1 = Blank
R2 = Blank
R3 = xxxxx, the address in memory where the identifier will be loaded if a correction is to be made.

TABLE 4.2.5-I

DSKY DISPLAYS ASSOCIATED WITH P27 (CSM)

DSKY	Initiated by	Purpose	Condition	Register
FL V21 N01	P27	Request load of index	R3 contains ECADR* where index is to be loaded; R1 displays data as loaded	R1 Blank (xxxxx) R2 Unchanged R3 xxxxx
FL V21 N01	P27	Request load of data	R3 contains address where data are to be loaded; R1 displays data as it is loaded	R1 Blank (xxxxx) R2 Unchanged R3 xxxxx
FL V21 N02	P27	Request load of octal identifier	R3 contains address where identifier is to be loaded	R1 Blank R2 Unchanged R3 xxxxx

*ECADR is an erasable memory constant.

TABLE 4.2.5-II

EXTENDED VERBS USED WITH P27 (CSM)

VERB	Identification	Purpose	Remarks
70 ENTR	Liftoff time update	Select P27 for liftoff time update	Refer to paragraph 4.2.5.1.1
71 ENTR	Contiguous block update	Select P27 to update from 1_8 to 22_8 consecutive erasable memory locations in the same EBANK*.	Refer to paragraph 4.2.5.1.2
72 ENTR	Scatter update	Select P27 to update from 1_8 to 11_8 not necessarily consecutive erasable memory locations.	Refer to paragraph 4.2.5.1.3
73 ENTR	Octal clock increment	Select P27 to increment or decrement the CMC clock	Refer to paragraph 4.2.5.1.4

* EBANK is an erasable memory bank.

To correct some of the update data, the crew can respond to the flashing VERB 21 NOUN 02 by keying in a 2-digit octal identifier followed by ENTR. The octal identifier specifies which piece of data (01 or 02) is to be changed. The DSKY then flashes VERB 21 NOUN 01 to request the new value. If an unacceptable octal identifier is entered, the program disregards the entry and continues to flash VERB 21 NOUN 02.

P27 verifies that the double precision octal time (i.e., the 10-digit number entered above) can be subtracted from the CMC clock without causing overflow. If the subtraction can be made, P27 proceeds to increment TEPHEM and decrement the CMC clock, the CSM state vector time, and the LM state vector time.*

4.2.5.1.2 VERB 71 ENTR.—VERB 71 allows the ground or the crew to initiate a contiguous erasable-memory update. VERB 71 can be used to load any contiguous block of erasable memory; but it is usually used to perform the following updates:

a. CMC CSM/LM state vector update
b. CMC desired REFSMMAT update
c. CMC REFSMMAT update
d. CMC External Δv update
e. CMC retrofire External Δv update
f. CMC entry update
g. CMC landing site vector update.**

The VERB 71 data are entered according to the following format:

II ENTR
AAAA ENTR
xxxxx ENTR
xxxxx ENTR
.
.
.
xxxxx ENTR

---

* TEPHEM is ephemeris time.

** Refer to Section 2, GSOP, paragraph 2.1.5, for a definition of each of these updates.

where:

II is a 2-digit octal number between 3_8 and 24_8—the index value representing the total octal number of numeric quantities to be loaded.

AAAA is the erasable memory address of the first data word of the update data block to be processed. For one data load operation, all update parameters must ultimately be stored in the same EBANK (erasable memory bank). Therefore, the starting address and the length of the block must be chosen so that the complete load can be contained in the same EBANK. Bits 1–8 of AAAA indicate the relative address ($0-377_8$) within the selected EBANK and bits 9–11 identify the desired EBANK (0–7). The format just described is the format of an erasable memory constant called an ECADR. The relative address plus the index minus 3 must be less than or equal to 377_8. The example below illustrates this explanation.

If the EBANK equals 3 and the relative address equals 306_8, AAAA would have the following bit configuration:

01 111 000 110

→ Bits 1 - 8 give the relative address within the EBANK

→ Bits 9 - 11 identify the desired EBANK

The crew would key in the octal value 1706.

xxxxx is octal data to be loaded.

The crew responds to the first request for data (flashing VERB 21 NOUN 01) by keying in the 2-digit octal index and visually verifying it (as displayed in R1) before keying ENTR. The program flashes VERB 21 NOUN 01 until a legal value is entered —as indicated by a change in the contents of R3. An incorrect index value perceived before ENTR has been keyed can be altered by keying CLR and keying in the correct value. Once an incorrect index value has been entered, the only means of recovering is to terminate the update (VERB 34 ENTR) and to re-initiate the update verb.

The second octal data word the crew enters must be the erasable memory address of the first word of the update block. The crew then loads the update parameters to be stored in sequential memory locations.

As each data word is loaded, a counter is incremented so that the last ENTR of the update sequence causes P27 to flash VERB 21 NOUN 02 to request acceptance, or modification, of the data. Keying in VERB 33 ENTR (data accepted) causes P27 to transfer the data to the specified block.

4.2.5.1.3 <u>VERB 72 ENTR</u>.—VERB 72 allows the ground or the crew to initiate an erasable memory update in not necessarily contiguous locations. The VERB 72 data format is as follows:

II ENTR
AAAA ENTR
xxxxx ENTR
AAAA ENTR
xxxxx ENTR
.
.
.
AAAA ENTR
xxxxx ENTR

where:

<u>II</u> is a 2-digit octal number between 3_8 and 23_8. The index II must always be odd since it includes the index and the address data pairs (i.e., AAAA and xxxxx). If the index entered is even when it is checked after VERB 33 ENTR, P27 will reject all the data and terminate.

<u>AAAA</u> is the erasable memory address of the location to be loaded with the xxxxx immediately following.

<u>xxxxx</u> is octal data to be loaded.

Except for the format, VERB 72 is operationally similar to VERB 71.

4.2.5.1.4 <u>VERB 73 ENTR</u>.—The crew keys VERB 73 ENTR to initiate a double-precision octal time increment. The loading procedure for this update is identical

to the VERB 70 update defined in paragraph 4.2.5.1.1. If the update data are acceptable, the data are used to increment the clock. No delay is encountered if the Orbital Integration Routine is in use, since the information used by that routine cannot be changed by the CMC clock update.

4.2.5.2 P27 Procedure

Figure 4.2.5-1 gives the logical flow of P27. Figure 4.2.5-2 gives two examples of manual data loads.

Before entering P27, the CMC major mode must be P00, P02, or P20 (options 1, 2, or 5) and the DSKY must be available.

P27 can be manually selected by the astronaut's keying in one of the four extended verbs on the DSKY. The program can also be selected by the ground via uplink transmission. If the latter is done, the crew must place the UP TLM ACCEPT/BLOCK switch to ACCEPT. The manual update is described in the following program procedures. Uplink update is done in the same way, except that the crew functions are performed from the ground.

P27 is entered by keying VERB 70 ENTR, VERB 71 ENTR, VERB 72 ENTR, or VERB 73 ENTR. If another extended verb, a marking display, or a priority display is active when one of the four verbs is keyed in, the DSKY will not be available, and P27 will illuminate the OPR ERR light. The crew should restart the program when the DSKY is free.

If the program being interrupted is not P00, P02 or P20 (options 1, 2, or 5), P27 will turn the OPR ERR light on and the UPLINK ACTY light off. The crew should place the UP TLM ACCEPT/BLOCK switch in BLOCK; CMC control will automatically return to the interrupted program.

If VERB 71 or VERB 72 is entered, the DSKY flashes VERB 21 NOUN 01 to request the loading of the index in the specified machine address. (R3 contains the machine address.) The index is the total number (in octal) of numeric values to be loaded—a minimum of 3_8 and a maximum of 24_8. The registers will appear as follows:

R1 = Blank
R2 = Unchanged
R3 = ECADR, the address at which the index will be loaded.

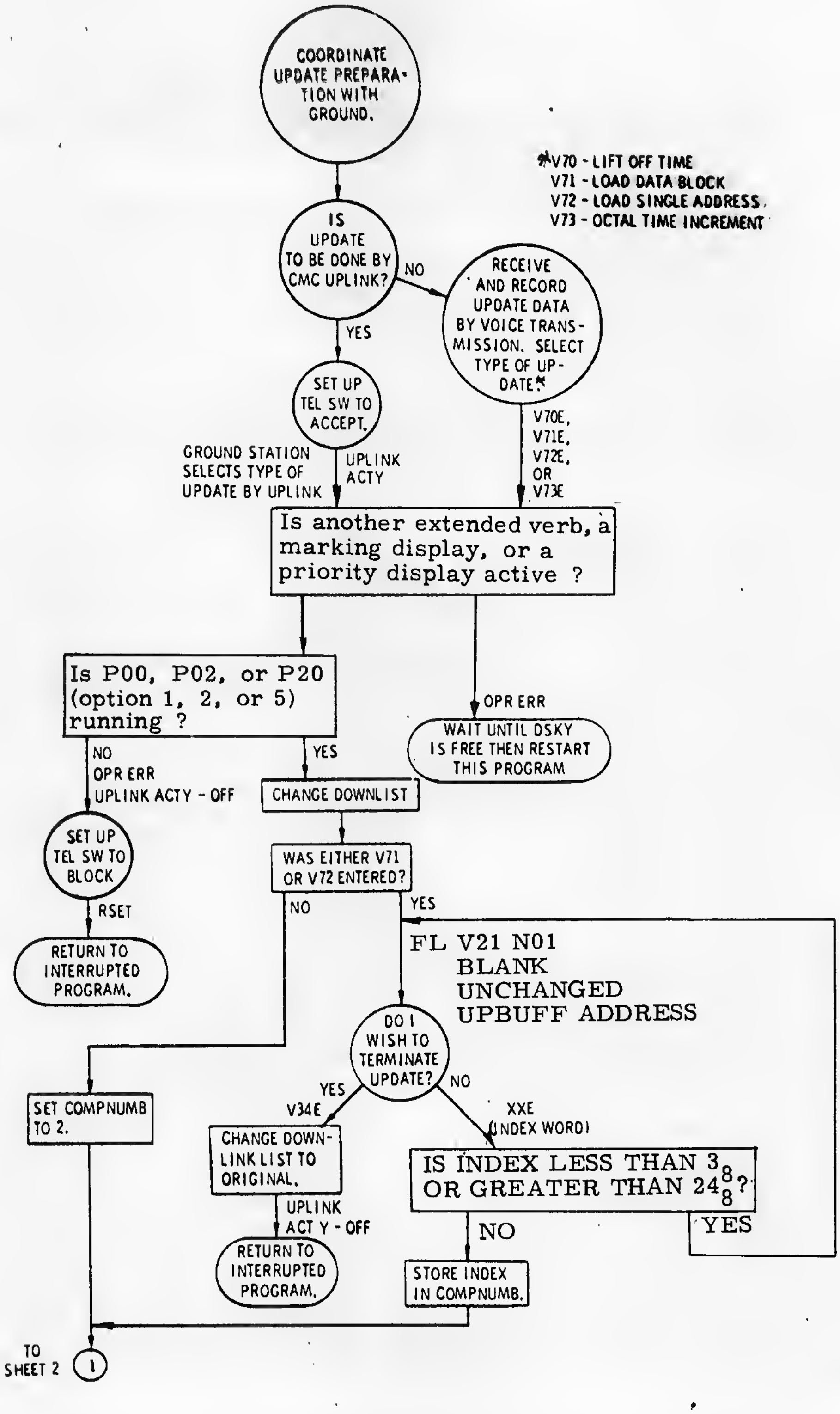


Figure 4.2.5-1. CMC Update Program (P27) (Sheet 1 of 3)

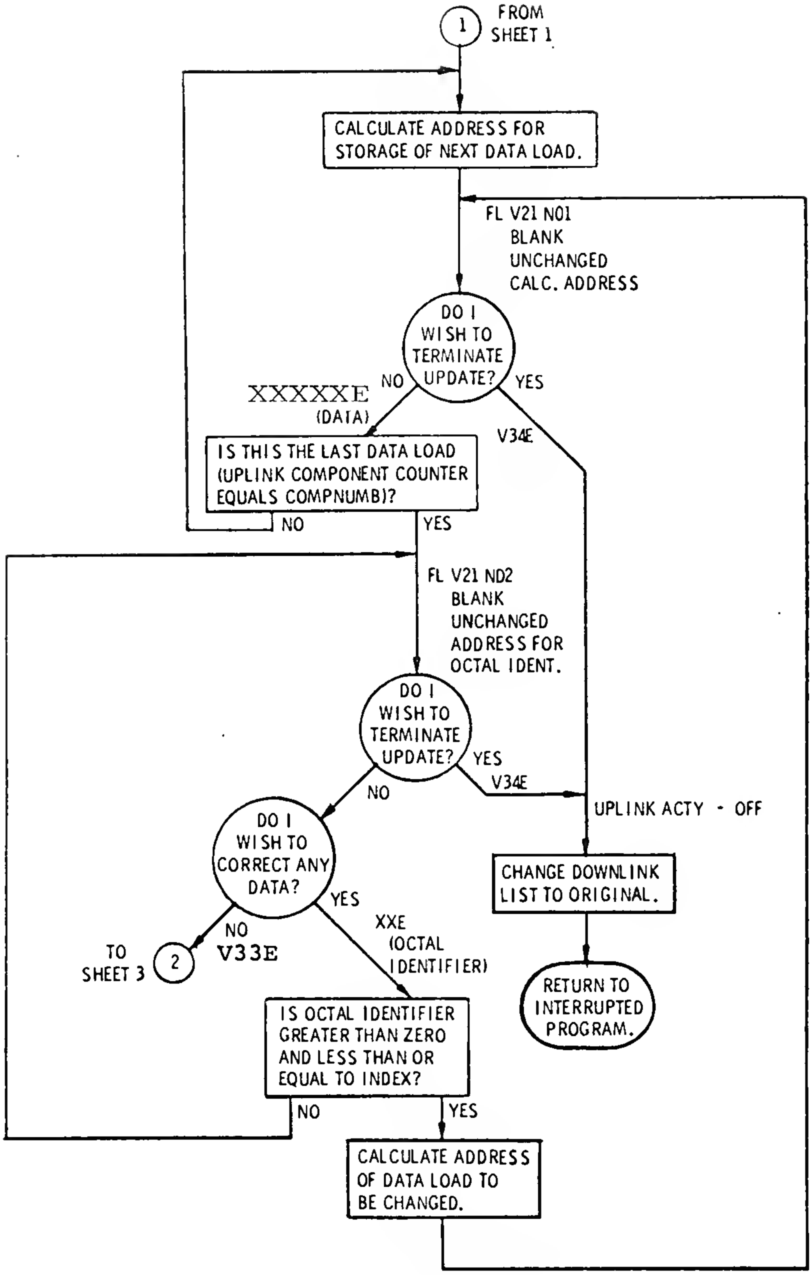


Figure 4.2.5-1. CMC Update Program (P27) (Sheet 2 of 3)

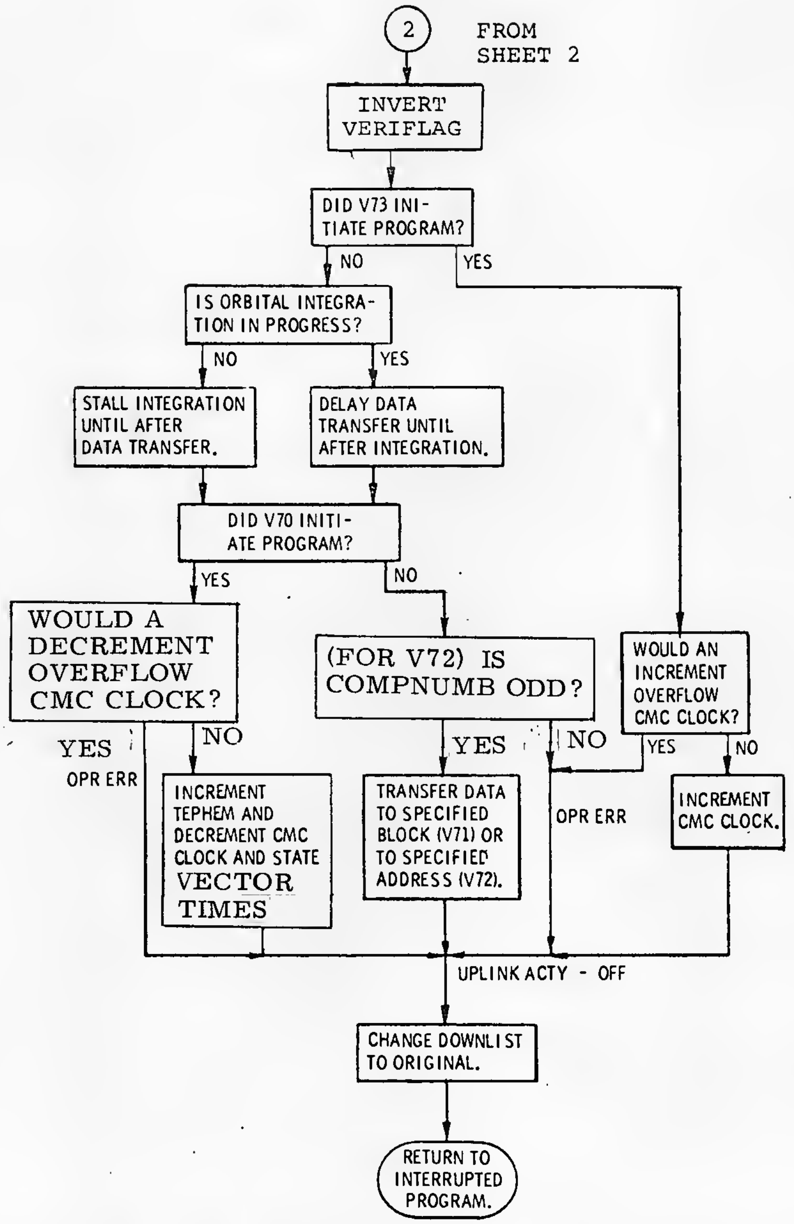


Figure 4.2.5-1. CMC Update Program (P27) (Sheet 3 of 3)

EXAMPLE 1: Load REFSMMAT (CM)

ENTRY		CMC RESPONSE	EXPLANATION
VERB 71 ENTR	→	FL VERB 21 NOUN 01	
24 ENTR			Octal number of numeric values to be loaded (including this one)
1733 ENTR			First erasable location
xxxxx ENTR			Data
⋮			
xxxxx ENTR	→	FL VERB 21 NOUN 02	Last data point
VERB 33 ENTR	→	P00 or P20	

EXAMPLE 2: Load CSM state vector in earth orbit

ENTRY		CMC RESPONSE	EXPLANATION
VERB 71 ENTR	→	FL VERB 21 NOUN 01	
21 ENTR			Octal number of numeric values to be loaded (including this one)
1501 ENTR			Code for state vector load
1 ENTR			Code for CSM state vector in earth orbit
xxxxx ENTR			Data
⋮			
xxxxx ENTR	→	FL VERB 21 NOUN 02	Last data point
VERB 33 ENTR	→	P00 or P20	

Figure 4.2.5-2. Examples of Manual Data Loads

The crew has the option of terminating the update at this point by keying in VERB 34 ENTR. If the crew terminates, the UPLINK ACTY light will go out and control will return to the program running at the time the update was initiated. Otherwise, the crew loads the index value, which is then displayed in R1 of the DSKY. If the index value is not within the limits (3_8 through 24_8), the flashing VERB 21 NOUN 01 display will return to the DSKY, requesting the load of the index value. If the index value is within the specified limits, the program stores the index.

P27 next increments UPBUFF for storage of the next data load. (UPBUFF contains the address of the temporary storage location of the data word.) The DSKY flashes VERB 21 NOUN 01 to request load of data into the UPBUFF address displayed in R3. The crew has the option of terminating the update at this point by keying in VERB 34 ENTR. (The UPLINK ACTY light would go off.) If the crew loads data into UPBUFF, the data loaded will be displayed in R1. P27 will continue to flash VERB 21 NOUN 01 and display loaded data in R1 until all of the data has been loaded, i.e., until the number of items entered equals the index value.

Next the DSKY displays a flashing VERB 21 NOUN 02 to request response. The crew has three possible responses:

a. To accept all the data by keying in VERB 33 ENTR*
b. To terminate the update by keying in VERB 34 ENTR
c. To correct an item by keying in the octal identifier to specify which of the data words will be corrected.

In the last case, if an illegal octal identifier (less than zero or greater than the index) is keyed in, the flashing VERB 21 NOUN 02 display will return. Otherwise, the program will calculate the address of the data word to be changed and will return to the second flashing VERB 21 NOUN 01 display.

After all the data have been corrected and VERB 33 ENTR has been keyed in, P27 makes the actual data transfer.

If P27 is entered by using extended VERB 73, the program increments the CMC clock. Illumination of the OPR ERR light indicates that an increment would have caused an overflow.

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* Although VERB 33 ENTR is usually the equivalent of PRO, for VERB 21–23 PRO is not accepted even for a manual load. VERB PRO is accepted, however.

If P27 is entered by using the other three extended verbs, the program determines if the state vector data are being used by the Orbital Integration Routine. If so, further P27 instruction executions are delayed until the integration is complete. A DSKY display of 27 as the major mode, a ground verification that BIT3 of FLAGWRD7 (VERIFLAG) has been inverted, and the absence of an OPR ERR notification should indicate to the crew that the completion of P27 is temporarily delayed. After P27 is reactivated, or if the Orbital Integration Routine is not in use, P27 will inhibit other routines from using state vector data.

If entered via VERB 70, P27 increments TEPHEM and decrements the CMC clock and state vector times. Illumination of the OPR ERR light indicates that decrement of the CMC clock would cause overflow.

If entered via VERB 71 or VERB 72, P27 transfers the data to the specified block (VERB 71) or address (VERB 72).

When transfer of data is complete, P27 turns the UPLINK ACTY light off, releases the state vector data for other routines, and reinstates the interrupted program.

4.2.5.3 Alarms

No program alarms are associated with P27. The OPR ERR light is illuminated if the crew attempts to enter P27 while another extended verb, marking display, or priority display is active; if the CMC is not in P00, P02 or P20 (options 1, 2, or 5), or if incrementing in VERB 73 (or decrementing in VERB 70) would cause the CMC clock to overflow. The program then turns off the UPLINK ACTY light and terminates.

4.2.5.4 Restrictions and Limitations

P27 is allowed to be entered only when the CMC is in P00, P02, or P20 (options 1, 2, or 5) and no other extended verbs, a marking display, or a priority display are active.

The number of numeric quantities which can be loaded is restricted as follows:

a. To 22_8 for VERB 71, because the capacity of the temporary storage buffer for input data is 24_8 words, and this must include the index count and the starting address

b. To 11_8 for VERB 72, because the maximum 24_8 data words must include an address for each data word and the index.

If the Orbital Integration Routine is running when P27 is ready to transfer data to permanent locations and if the update is other than VERB 73, P27 will be delayed until the Orbital Integration Routine is terminated. While the transfer of data is taking place, use of the state vector data is inhibited. This restriction was made to avoid use of partially updated state vector information.

4.2.5.5 Ground Uplink Format

Information received by the CMC from the uplink is in the form of keyboard characters. Each character is assigned a character code number (C). Each character code transmitted to the CMC is sent as a triply redundant uplink word with a leading 1 bit. Thus, the 16-bit uplink word has the form:

$1 \ C \ \overline{C} \ C$

- C → 5-bit character code
- $\overline{C}$ → complement of 5-bit character code
- C → 5-bit character code
- 1 → leading 1 bit.

where $\overline{C}$ denotes the bit-by-bit complement of the 5-bit C. To these 16 bits of information, the ground adds a 3-bit code specifying the system aboard the spacecraft that is to be the final recipient of the data and a 3-bit code indicating the spacecraft that should receive the information. The 22 total bits are further encoded bit-by-bit (i.e., each bit is replaced with a 5-bit code for transmission). If the message is received and successfully decoded, the on-board receiver will send back an 8-bit-message-accepted pulse to the ground and shift the original 16 bits of the uplink word to the CMC. The leading 1 bit causes an interrupt within the CMC after all 16 bits have been shifted from the uplink receiver. It is good operational procedure to end every uplink message with KEY RELEASE. (Table 4.2.5-III gives the uplink words for all legal input characters.)

If the CMC receives an improperly coded word from the uplink receiver during the load, it notifies the ground by setting BIT4 of FLAGWRD7 to 1 and transmitting it via downlink. When this occurs, the ground station should correct the transmission by sending the following uplink word:

1 00000 00000 00000

TABLE 4.2.5-III

LEGAL INPUT CHARACTERS AND ASSOCIATED UPLINK WORDS (CSM P27)

Character	Uplink Word (Binary)			
0	1	10000	01111	10000
1	1	00001	11110	00001
2	1	00010	11101	00010
3	1	00011	11100	00011
4	1	00100	11011	00100
5	1	00101	11010	00101
6	1	00110	11001	00110
7	1	00111	11000	00111
8	1	01000	10111	01000
9	1	01001	10110	01001
VERB	1	10001	01110	10001
NOUN	1	11111	00000	11111
ENTER	1	11100	00011	11100
ERROR RESET	1	10010	01101	10010
CLEAR	1	11110	00001	11110
KEY RELEASE	1	11001	00110	11001
+	1	11010	00101	11010
-	1	11011	00100	11011

and follow this by transmitting ERROR RESET. (Keying RSET on the DSKY would have no effect.) If CLEAR is transmitted immediately following ERROR RESET, the ground can then begin the corrected transmission with the first digit of the 5 octal digits that were being sent when the condition occurred. CLEAR is used after ERROR RESET to blank the data display register (R1). The ground station should then resume the update function by retransmitting the word beginning with the first octal character. If the ground wishes to continue loading without transmitting CLEAR, it must determine which character was in error when failure occurred, and resume uplink transmission from the point of failure. The determination can be made by monitoring the display in R1.

4.2.5.6 Restart

P27 is restart protected after data are verified by ground except for (1) a small window (place) in the clock updates (VERB 70 and VERB 73) and (2) a small window immediately after verification. Should a restart occur during a clock update, the crew should check the clock carefully, upon completion of P27, to see that it has been correctly updated. Should a restart occur before data have been verified, the crew must reselect P27. Should a restart occur immediately after ground verification, the crew should check that the uplink data have been processed.

4.2.6 P24, Rate-aided Optics Tracking—CMC

The Rate-aided Optics Tracking Program (P24) provides the command-module pilot (CMP) with a means of automatic landmark acquisition and with CMC assistance in tracking the acquired target. The major differences between P24 and P22 are (1) P22 provides no tracking assistance, and (2), except for its own use, P24 performs no onboard calculations with the tracking data accumulated: the data are automatically transmitted to the ground and processed there to refine knowledge either of the CSM orbit or of the landmark's location. Inputs to the program are (a) the landmark's latitude, longitude, and altitude above the mean lunar radius (in earth orbit, above the Fischer ellipsoid); (b) optical line-of-sight measurements. Outputs transmitted for ground computations are the three IMU angles, two optics angles (shaft and trunnion), and the time of the mark.

The principal advantage of P24 is that it makes landmark tracking feasible at much lower altitudes than is possible by manual tracking.

4.2.6.1 Geometry

At an altitude of 8 n. mi., the time required for the CSM to pass from the horizon (looking from a point along the flight path) to directly overhead is about 128 seconds. (Refer to Figure 4.2.6-1.) From the time that the CSM is 26 deg above the horizon until it is directly overhead (TCA) is about 20 seconds. Assuming that 26 deg is the minimum elevation from which visual acquisition of a landmark can be made, the maximum time available for tracking is about 40 sec, i.e., 20 sec before TCA, and 20 sec after TCA—for a tracking arc of 128 deg. Consistent with the principles of recursive navigation (paragraph 4.1.2), the nominal marking schedule calls for five marks, spaced evenly from TCA -20 sec, -10 sec, 0, +10 sec, and +20 sec.*
This distribution ensures the best combination of low-angle measurements (for altitude determination) and high-angle measurements (for position determination).

4.2.6.2 Optics Cone of Acquisition

The fixed axis of the optics rotating shaft lies within the spacecraft's X,Z plane and is depressed 57 deg from the spacecraft X-axis. Rotating the shaft provides

*In practice, the crew may take several more than five marks. The tendency is to begin marking as soon as the landmark is acquired and to continue tracking and marking until acquisition is lost. This is an acceptable procedure, since ground computation will be based on a weighted average.

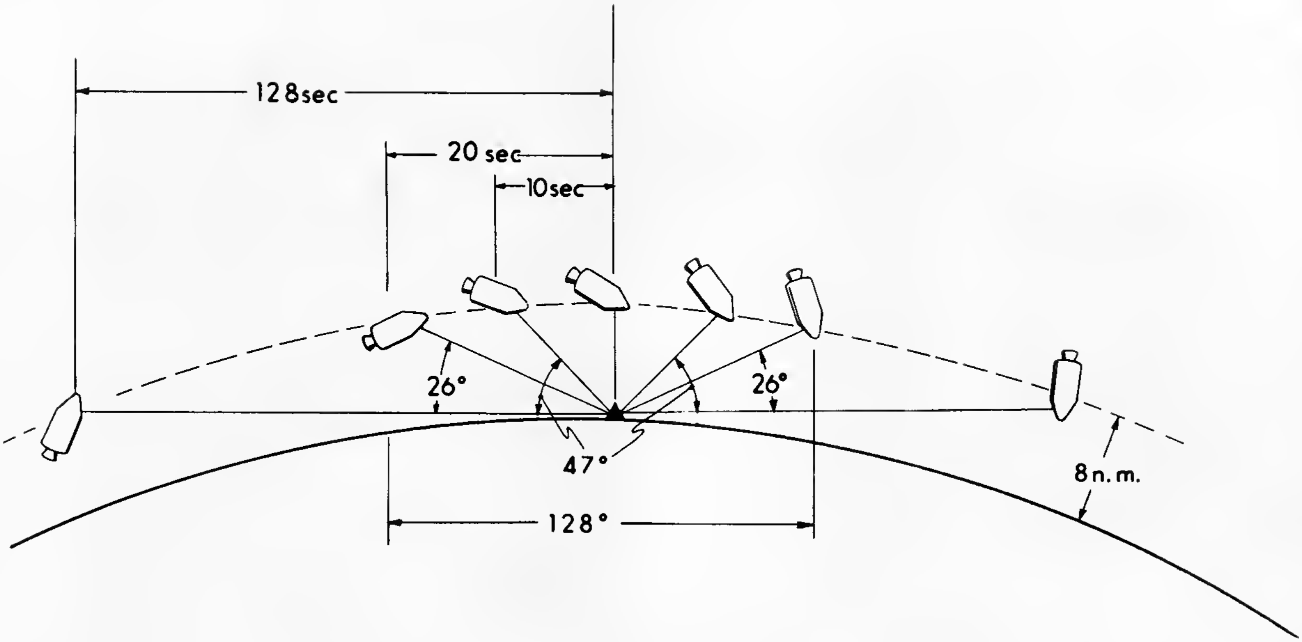


Figure 4.2.6-1. Lunar-landmark Tracking Geometry

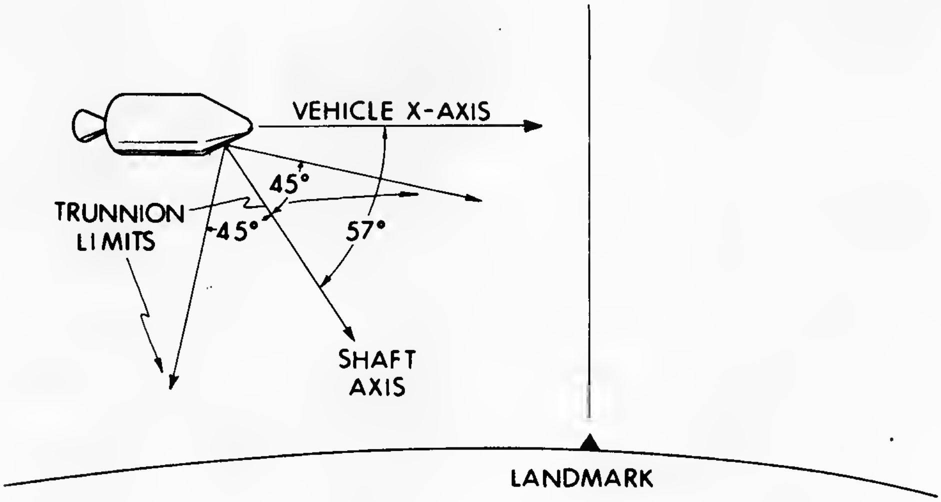


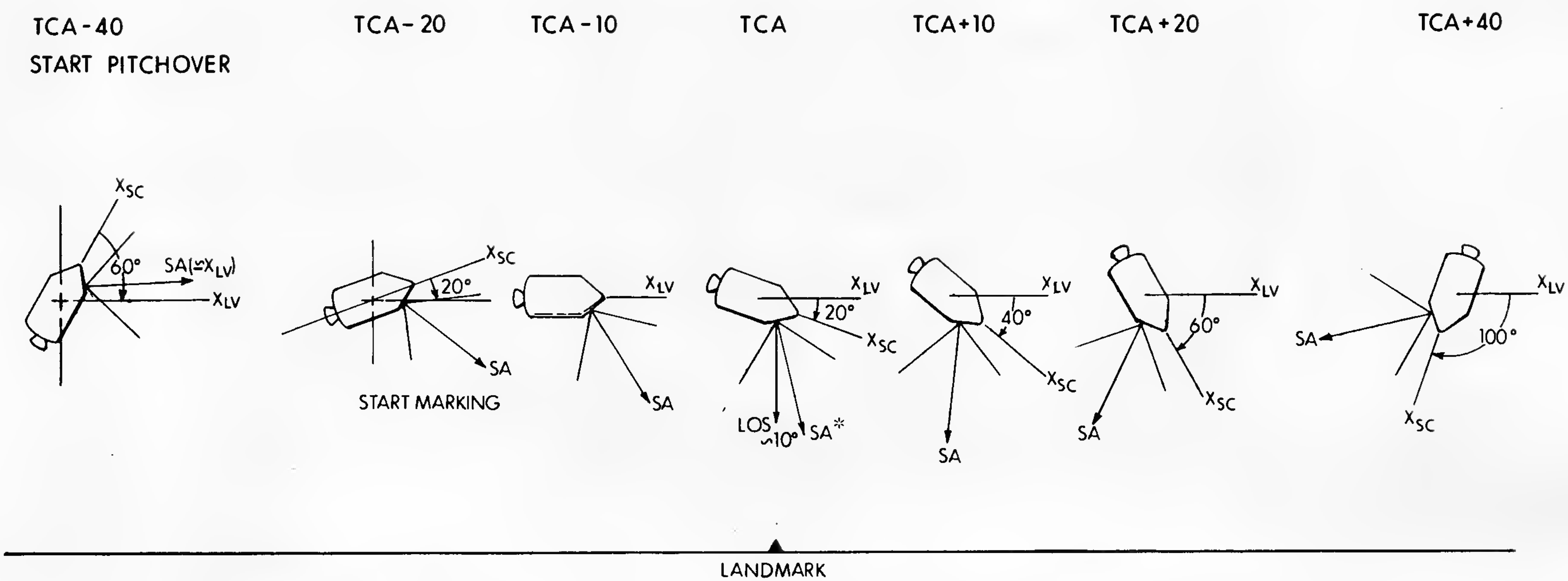
Figure 4.2.6-2. Optics Cone of Acquisition

360 deg of azimuth. The trunnion axis, in turn, can be elevated from zero to approximately 45 deg. Thus, rotating the shaft and elevating the trunnion allows the crew to acquire any target within a 90-deg cone. (See Figure 4.2.6-2.) To acquire a target outside the cone, the crew must rotate the spacecraft around an appropriate spacecraft axis.

Spacecraft rotation during landmark tracking has three functions: (1) to maintain the target within the cone of acquisition; (2) to decrease the tracking rate (LOS rate) required of the optics; and (3) to direct the optics shaft axis slightly out of the orbital plane in order to avoid an abrupt 180-deg rotation at the cone's vertex (trunnion angle, 0 deg). During P24, all spacecraft rotation is controlled by Option 2 of the Universal Tracking and Rendezvous Navigation Program (P20)—paragraph 4.2.1.

Maintaining the landmark within the 90-deg cone during the entire 128-deg tracking arc is accomplished by beginning tracking with the spacecraft pitched up and then initiating a pitch rate that will maintain the landmark within the cone as the landmark passes from 12 to 6 o'clock beneath the spacecraft. (Refer to Figures 4.2.6-3 and -4.) Directing the optics shaft axis out of the orbital plane is accomplished by establishing a roll attitude to effect the desired displacement and by then coordinating roll, pitch, and yaw to maintain the displacement constant throughout the maneuver. From the CMP's viewpoint, the attitude maneuver should look something like the first half of an aircraft outside loop with one wing down—rudders maintaining plane. Figure 4.2.6-4b shows the relationship of the flight path to the cone of acquisition when the optics shaft axis is skewed 20 deg out of the orbital plane. As a target nears the vertex, the shaft rotation rate required to track the target increases, reaching infinity at zero trunnion angle. Figure 4.2.6-4a shows what the relationship of flight path to acquisition cone would be if the optics shaft were not skewed (wings level). Note that an abrupt, 180 deg rotation of the optics shaft would be necessary to track a target passing through the cone's vertex.

Even with the shaft skewed out of the flight plane, shaft rotation can become excessive at the time of closest approach—i.e., when the tracking (LOS) rate is greatest. To avoid, therefore, the simultaneous occurrence of maximum shaft rate (shaft rotation angle = 90 deg) and maximum LOS rate, the spacecraft pitch-initiation time is calculated such that the shaft axis is pitched 10 to 20 deg either beyond or behind



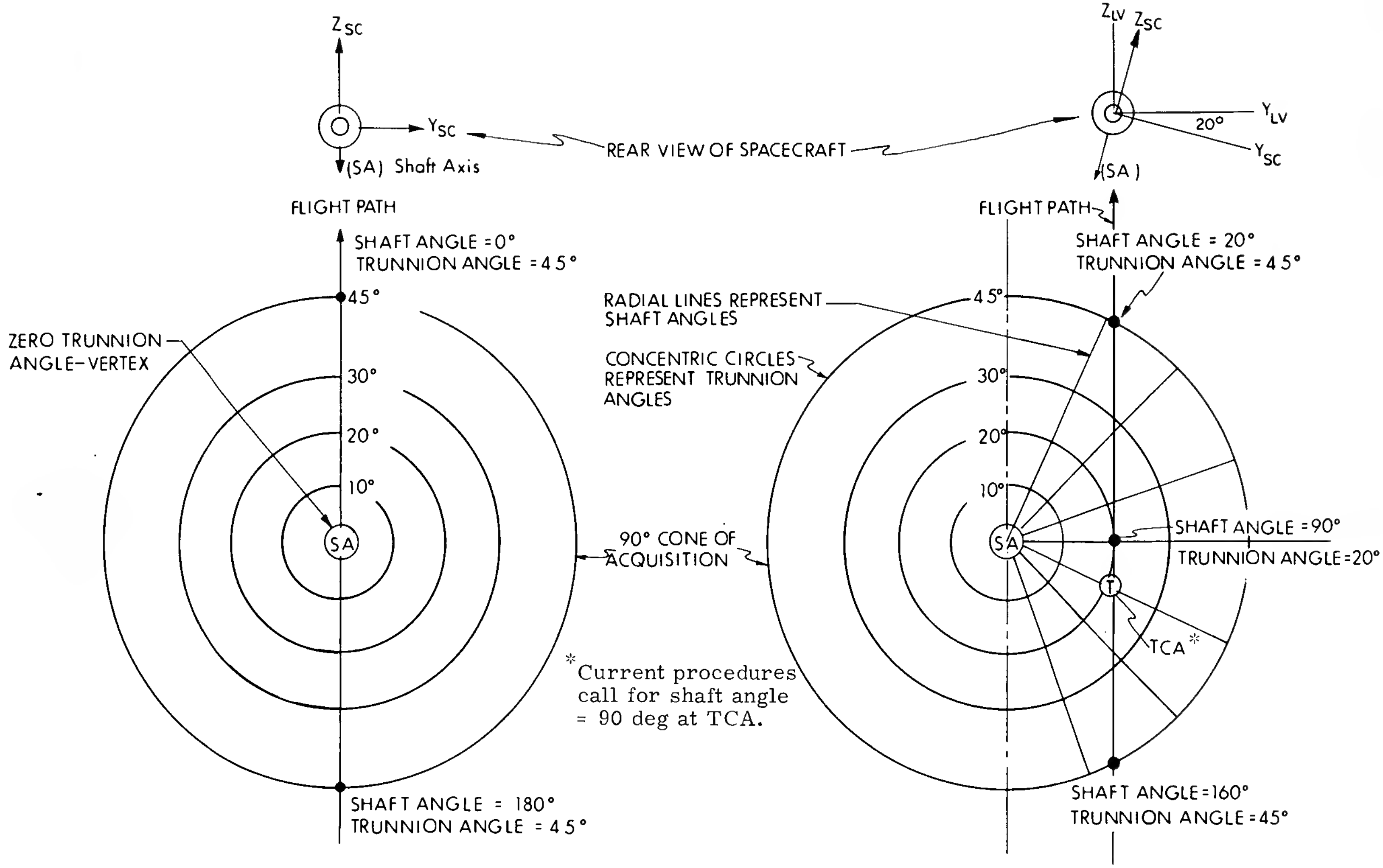
X_{SC} = SPACECRAFT X-AXIS

X_{LV} = LOCAL VERTICAL X-COORDINATE

SA = OPTIC SHAFT AXIS

*Current procedures call for zero forward displacement of SA from TCA LOS.

Figure 4.2.6-3. Typical Pitch Attitude During Landmark Tracking (Low Orbit)



a. Zero Roll, Shaft Axis in Orbital Plane

b. Twenty Degrees Right Roll, Shaft Axis Deflected out of Orbital Plane.

Figure 4.2.6-4 Bird's-eye View of Flight Path Overlayed by Polar Coordinates of Optics Cone of Acquisition

the target at TCA.* Accordingly, Figure 4.2.6-3 shows the shaft axis at TCA pitched $\simeq$10 deg forward of the LOS—or $\simeq$80 deg below local horizontal. Since the fixed shaft axis is depressed 57 deg from the spacecraft X-axis (θ), the desired condition obtains when the spacecraft X-axis is 20 deg below local horizontal (ϕ): $\phi + \theta = 77$ deg.

Similarly, the shaft axis at TCA is pitched $\simeq$10 deg behind the LOS (or $\simeq$100 deg below local horizontal) when the spacecraft X-axis is 45 deg below horizontal: $\phi + \theta = 102$ deg. Unacceptable pitch attitudes at TCA, therefore, are those between -20 and -45 deg local horizontal.

Figure 4.2.6-5 graphs the pitch initiation time (t) for various initial spacecraft pitch attitudes (ϕ_{INIT}), pitch attitudes at closest approach (ϕ_{TCA}) and a pitch rate ($\dot{\phi}$) of 2 deg/sec:

$$t = \frac{\phi_{TCA} - \phi_{INIT}}{\dot{\phi}},$$

where in this example (see note), ϕ_{TCA} is constrained (local horizontal):

$$-45 \text{ deg} > \phi_{TCA} > -20 \text{ deg}.$$

4.2.6.3 Sequence of Events

The rate-aided optics sequence begins when, in P00, the CMP calls the Crew-defined Maneuver Routine (R62) to perform an attitude maneuver to the initial tracking attitude. This is accomplished about 10 minutes before the time of closest approach (TCA).

At about TCA-5 minutes, the CMP calls the Universal Tracking and Rendezvous Navigation Program (P20); selects Option 2; specifies the desired axis of rotation, rate, deadband, and time (GET) to begin the maneuver.

The CMP then calls P24 (Figure 4.2.6-6) and loads the target parameters—latitude, longitude (divided by two for scaling), and altitude. Next, he causes P24 to call the

*Flight experience has shown that simultaneous occurrence of maximum shaft rate and maximum LOS rate presents no problem when P24 is used with present mission orbits. Current procedures, therefore, call for the optics shaft axis to be in line with the LOS at TCA, i.e., for the spacecraft X-axis at TCA to be 33 deg below local horizontal. The excluded range for ϕ_{TCA}, therefore, is not currently applicable. See, also, Figures 4.2.6-3, -4, and -5.

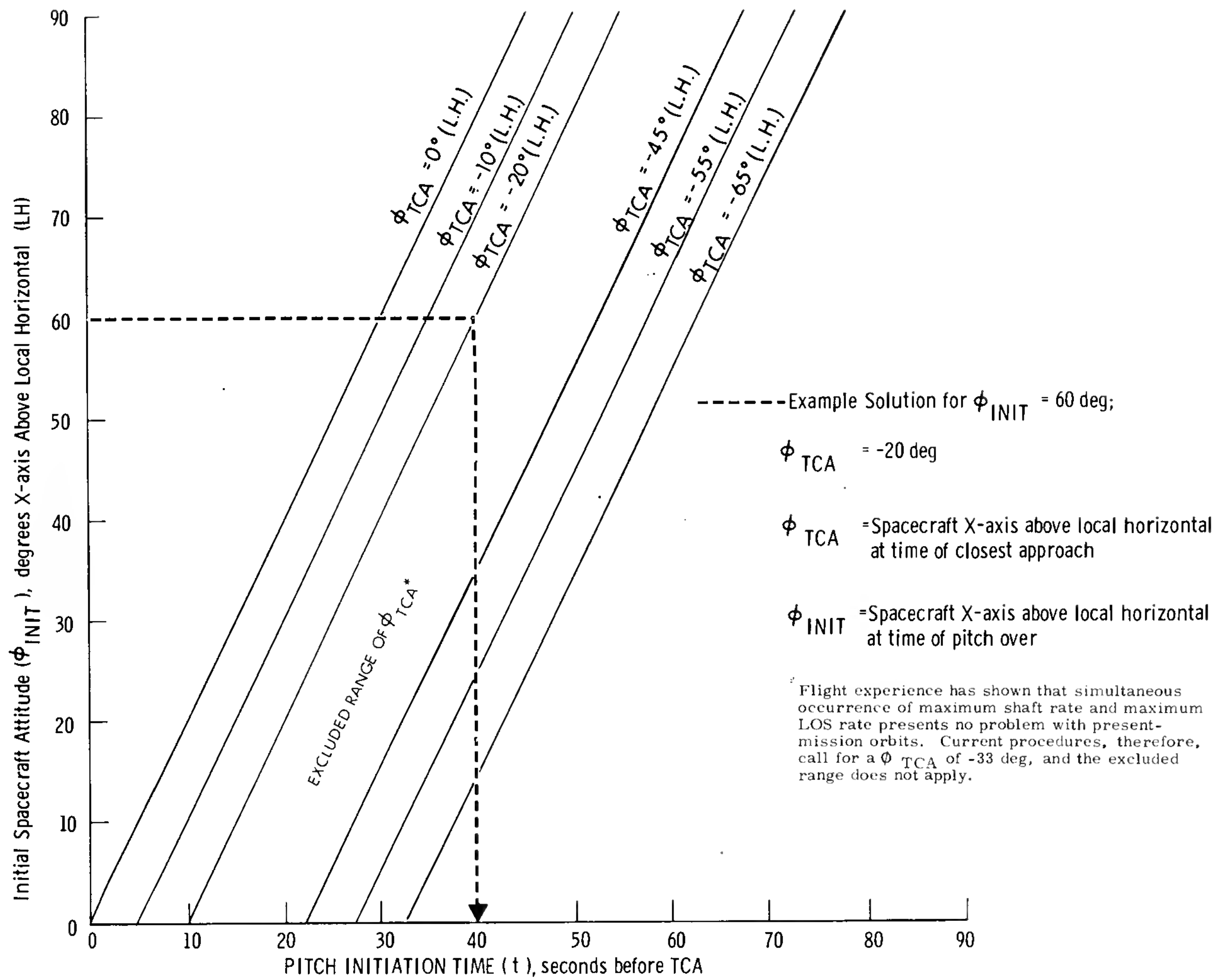


Figure 4.2.6-5. Pitch-initiation Time for P24 Landmark Tracking (Pitch Rate = 2 deg/sec)

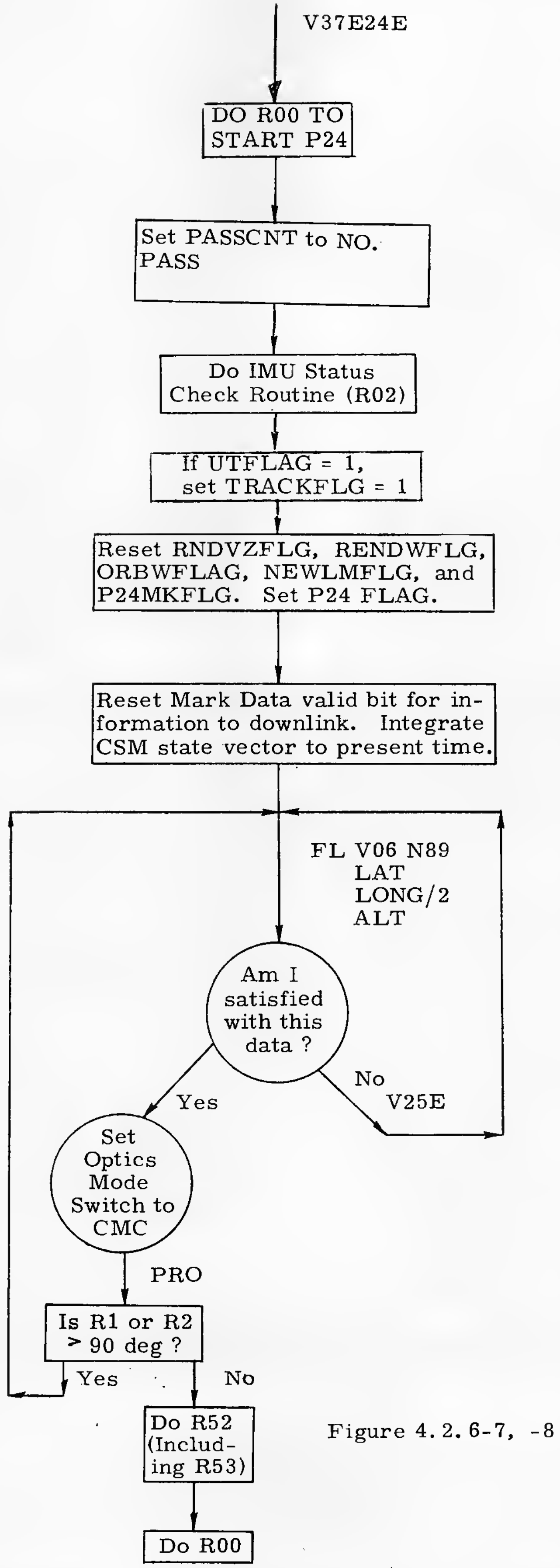


Figure 4.2.6-6. Rate-aided Optics Tracking Program (CSM P24)

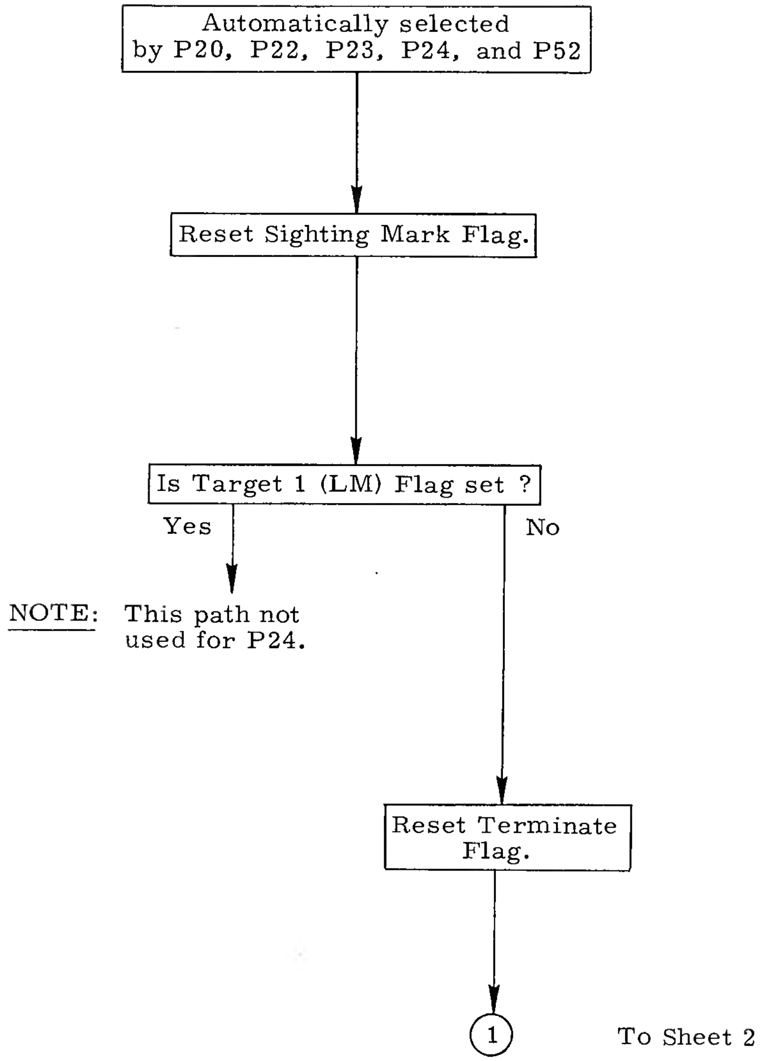


Figure 4.2.6-7. Automatic Optics Positioning Routine (CSM R52) (Sheet 1 of 5)

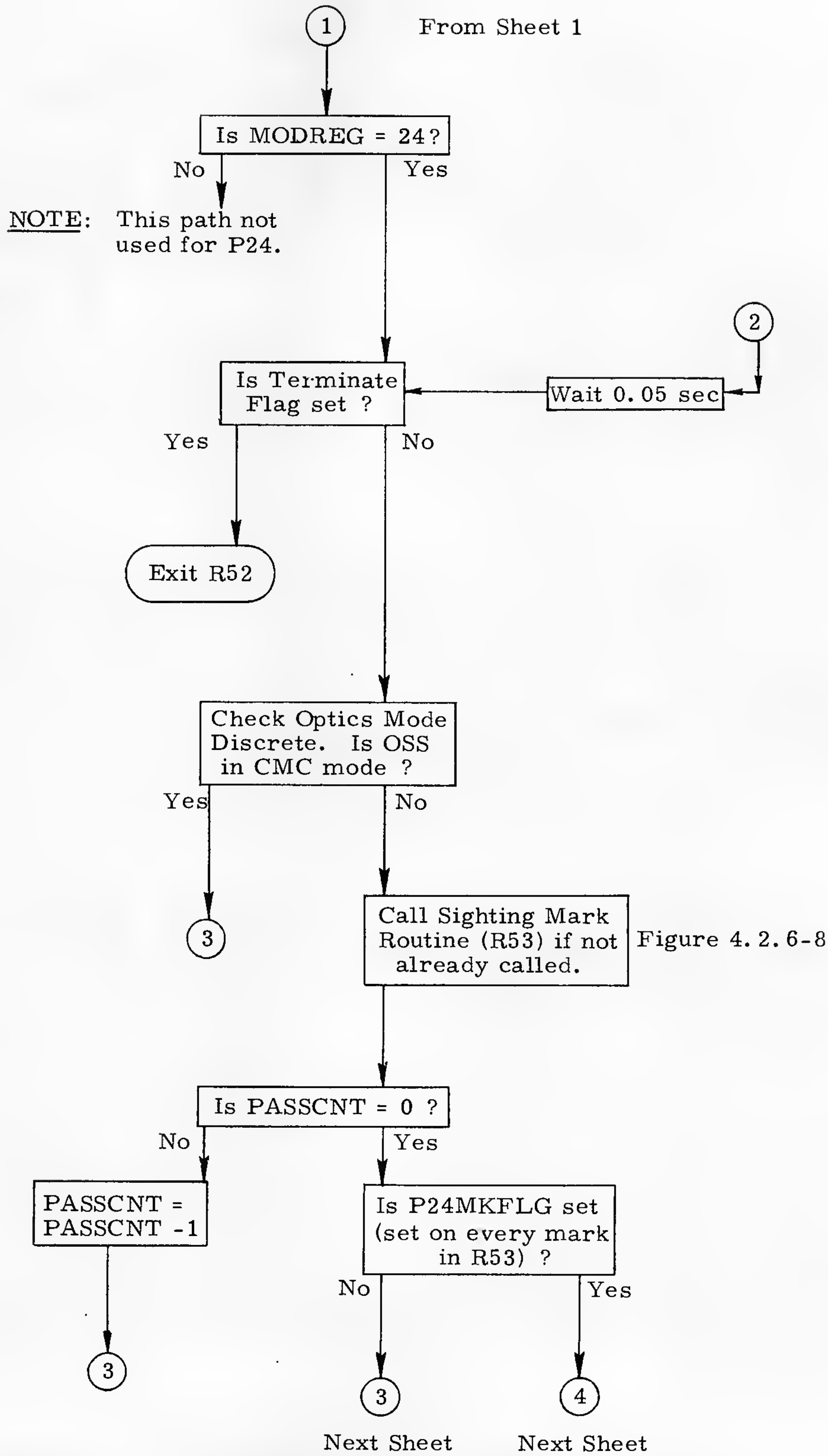


Figure 4.2.6-7. Automatic Optics Positioning Routine (CSM R52) (Sheet 2 of 5)

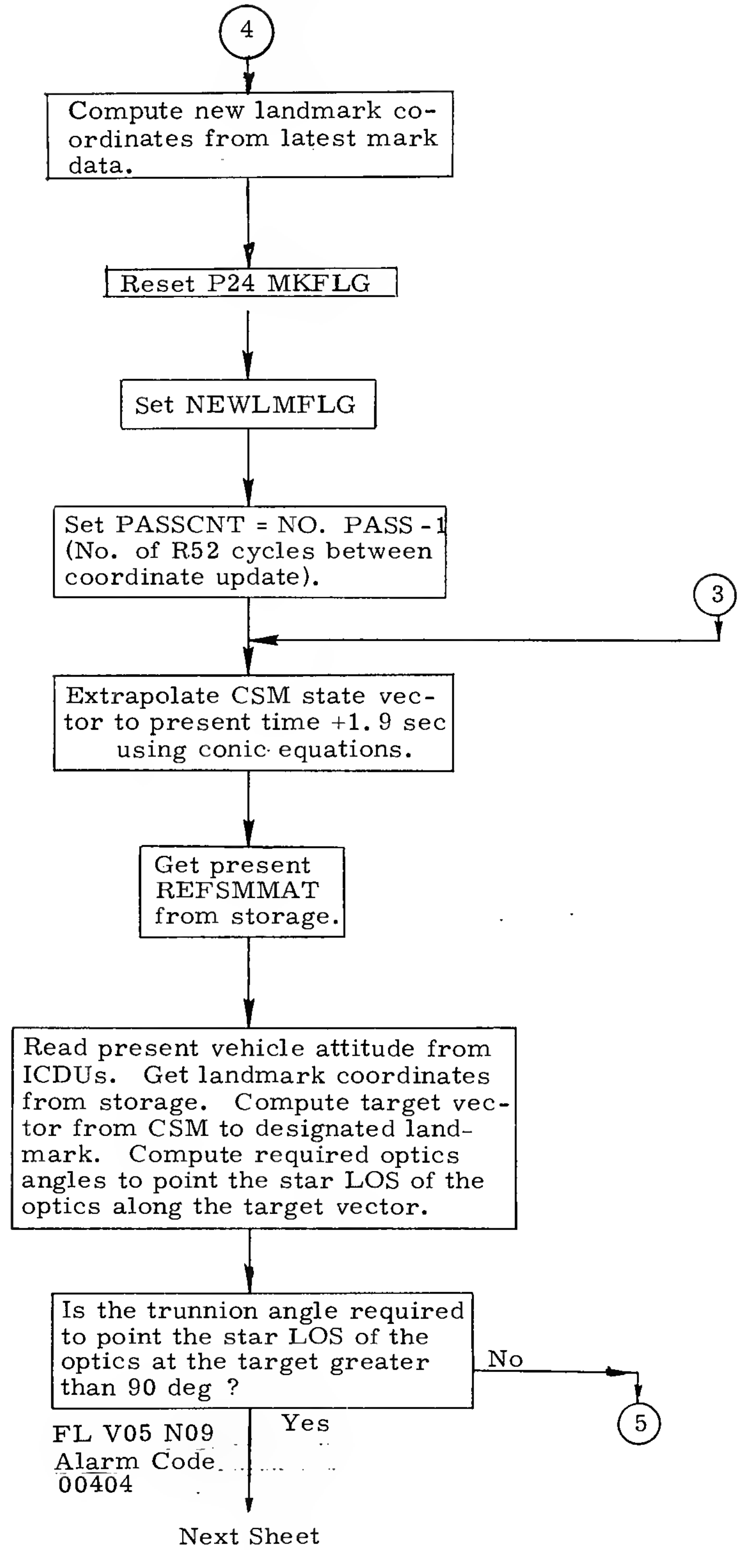


Figure 4.2.6-7. Automatic Optics Positioning Routine (CSM R52) (Sheet 3 of 5)

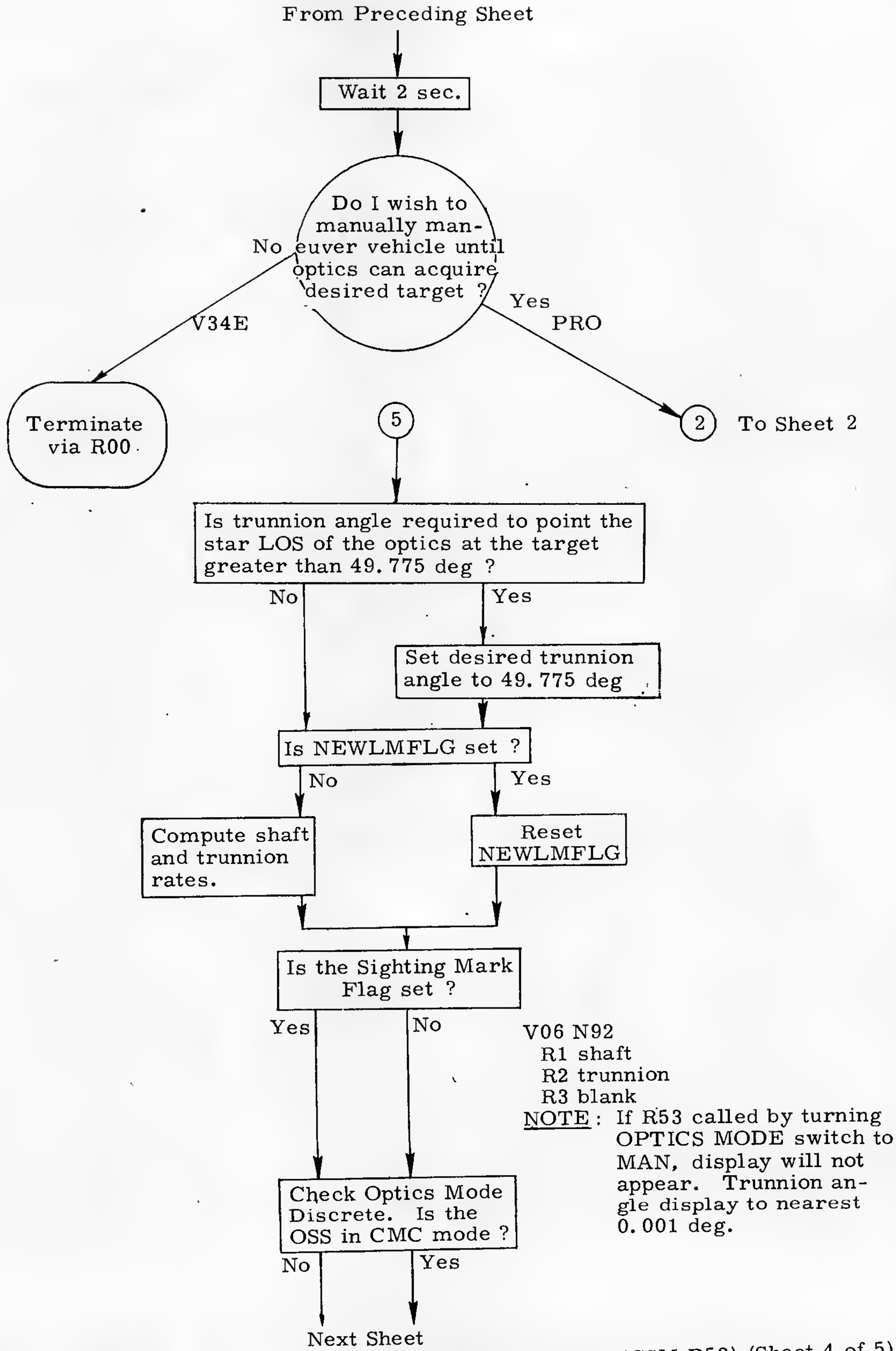


Figure 4.2.6-7. Automatic Optics Positioning Routine (CSM R52) (Sheet 4 of 5)

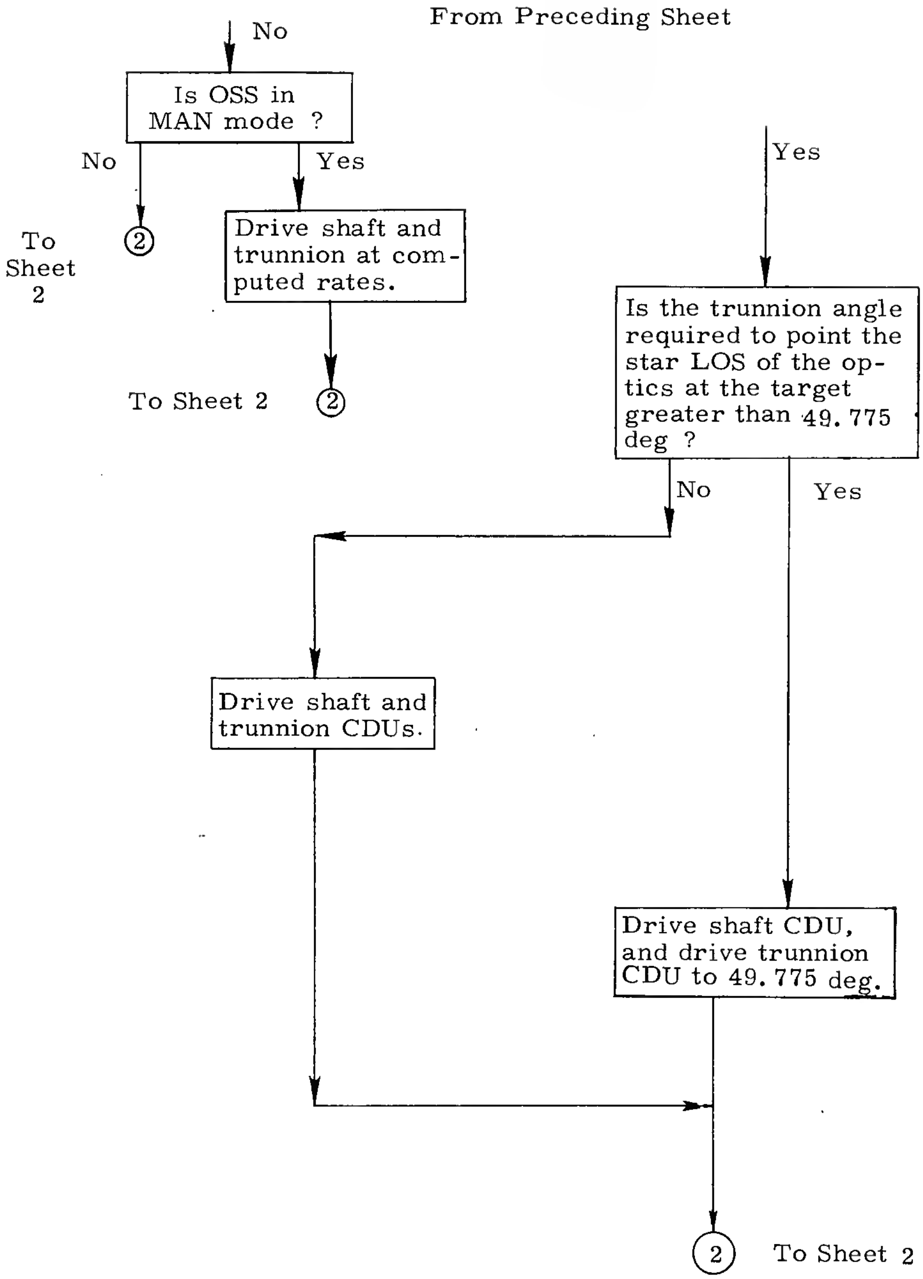


Figure 4.2.6-7. Automatic Optics Positioning Routine (CSM R52) (Sheet 5 of 5)

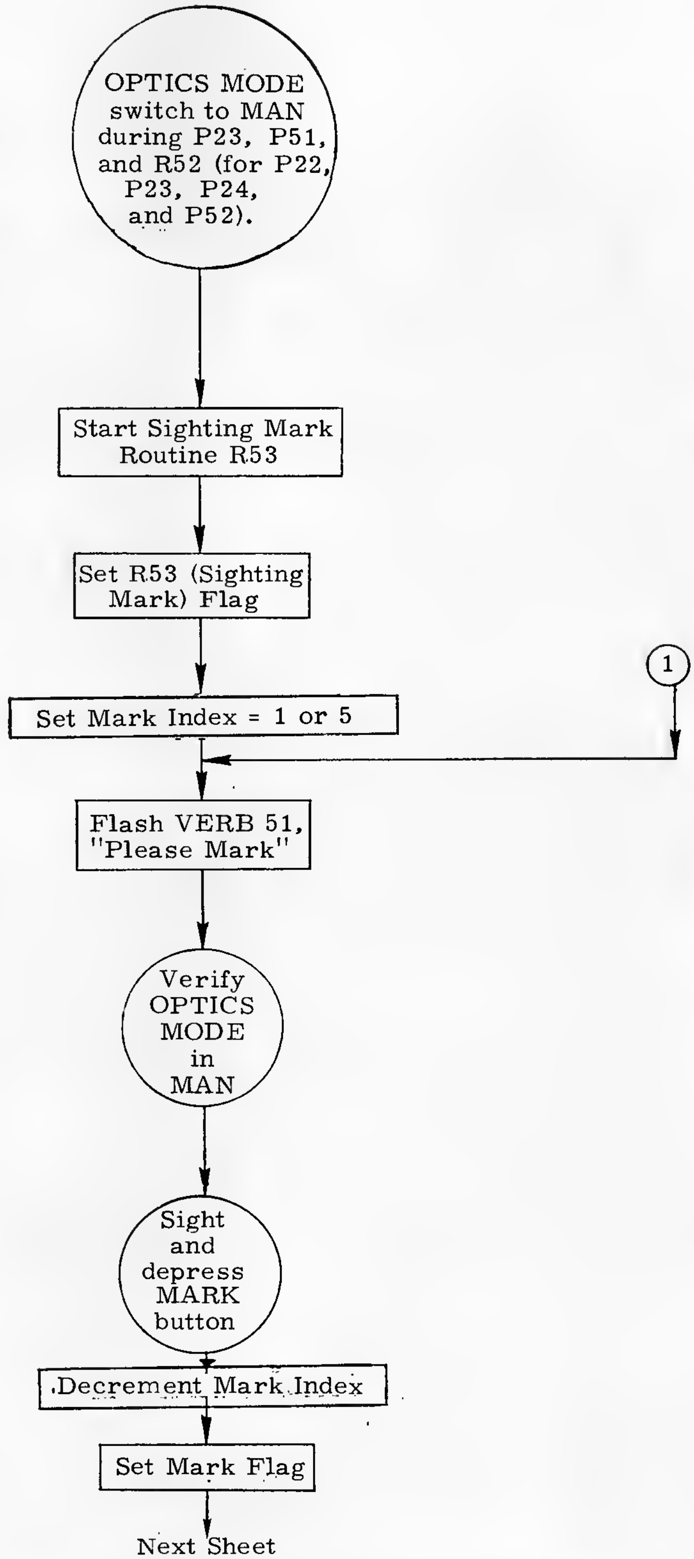


Figure 4.2.6-8. Sighting Mark Routine (CSM R53) (Sheet 1 of 4)

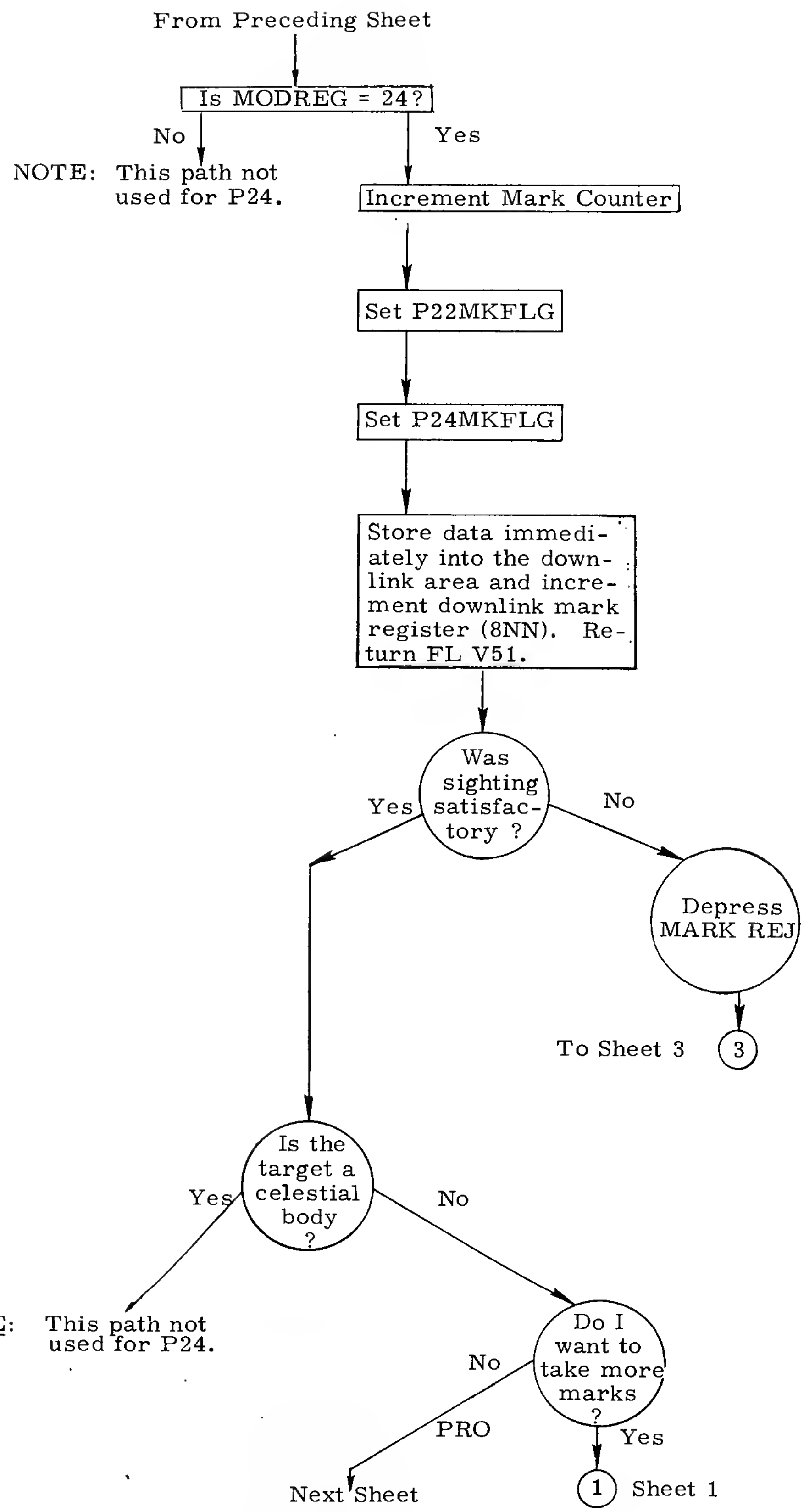


Figure 4.2.6-8. Sighting Mark Routine (CSM R53) (Sheet 2 of 4)

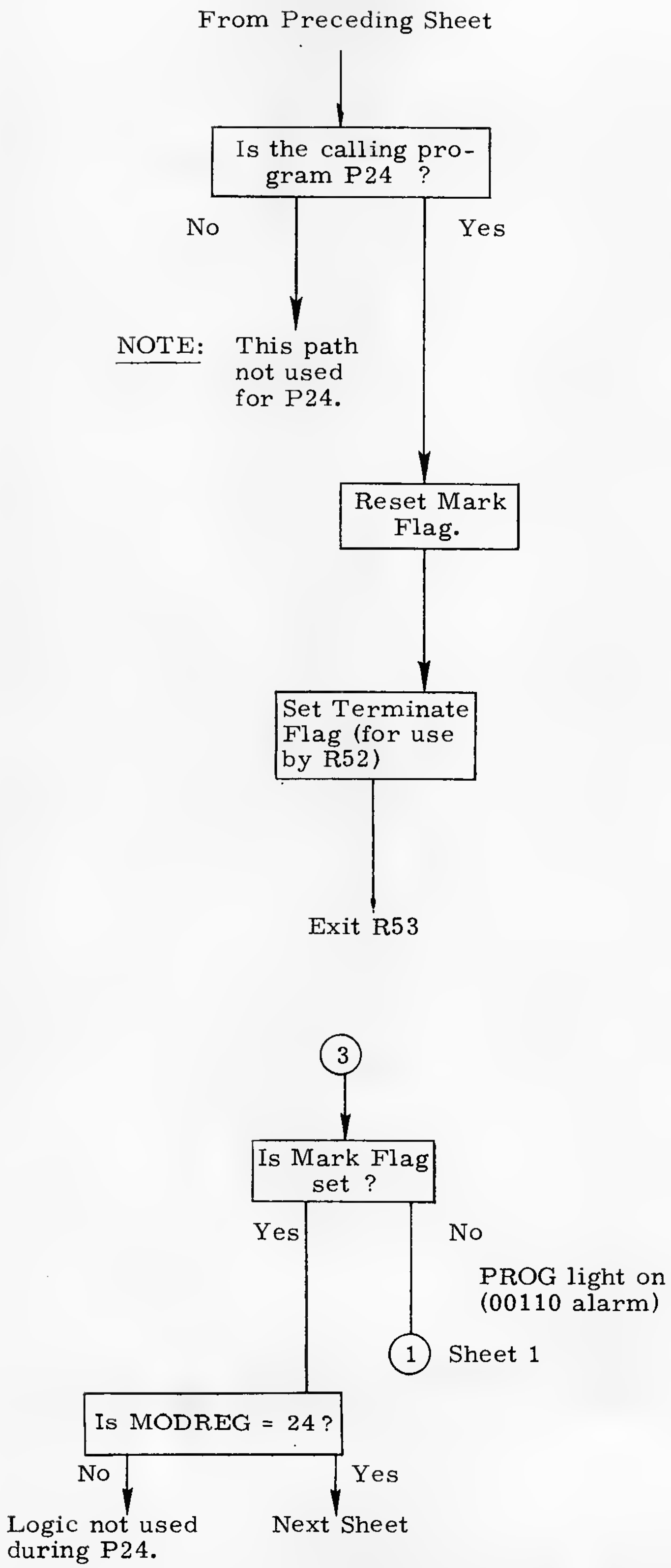


Figure 4.2.6-8. Sighting Mark Routine (CSM R53) (Sheet 3 of 4)

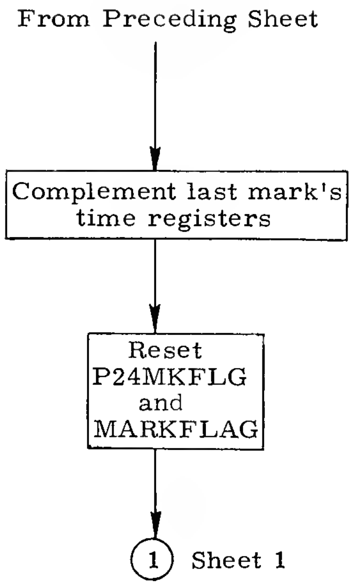


Figure 4.2.6-8. Sighting Mark Routine (CSM R53)(Sheet 4 of 4)

Automatic Optics Positioning Routine (R52, Figure 4.2.6-7), which displays and positions the optics shaft and trunnion angles for acquiring the landmark.

When the landmark has been acquired within the scanning telescope (SCT) field of view—and the DAP has established a controlled rate of S/C rotation—the CMP calls the Sighting Mark Routine (R53, Figure 4.2.6-8)—by switching the OPTICS MODE switch to MANUAL—and begins to use the optics hand controller to track the landmark. Every 1.3 sec, however, R52 computes a new line of sight to the target, as well as the rate of LOS change. This rate is input to drive the shaft and trunnion automatically; consequently, an approximate tracking condition is established and maintained independent of crew action. The crew's use of the handcontroller is necessary, however, both for refining the tracking and for making the small adjustments required to keep the crosshairs centered on the landmark. Mark data (three gimbal angles, two optics angles, time of mark) are loaded immediately into the downlink area for the ground to use in computing the orbit or the location of the landmark, depending upon which is the dependent variable. To avoid the possibility of lost data, the crew should use the onboard recorder to store the data for later transmission and processing.

When marking has been completed, the rate-aided optics sequence ends and P24 exits.

4.2.6.4 Procedures

A chronological summary of P24 displays and procedures is presented as Table 4.2.6-I. An amplified description of the procedures will be presented here.

A. Preliminary

1. At approximately 10 minutes before the time of closest approach (TCA), set the SC CONT switch to CMC and the CMC MODE switch to AUTO. This configuration is necessary in order for the DAP to perform the required attitude maneuver when specified.
2. While in P00 (VERB 37 ENTR 00 ENTR), call the Crew-defined Maneuver Routine (R62, VERB 49 ENTR). Upon flashing VERB 06 NOUN 22, key VERB 25 ENTR and load desired final gimbal angles for an attitude maneuver to the initial tracking attitude. Key PRO to call the Attitude Maneuver Routine (R60).

3. Upon flashing VERB 50 NOUN 18 ("Please perform attitude maneuver" to the final gimbal angles displayed), key PRO to have maneuver performed automatically.
4. Monitor FDAI Ball and Attitude Error Needles; be prepared to use the rotational handcontroller (RHC), if necessary, to avoid gimbal lock. The DSKY display during the maneuver is a nonflashing VERB 06 NOUN 18 (final gimbal angles).

   NOTE.—A MGA of ±75 deg causes maneuver to terminate. Use RHC to complete maneuver manually.

5. At maneuver completion, the flashing VERB 50 NOUN 18 returns. If the displayed gimbal angles do not agree—within RCS DAP deadband limits—with the present attitude, key PRO to recycle (trim). When the desired attitude is achieved, key ENTR to exit R62/R60.
6. Upon completion of the maneuver, key VERB 37 ENTR 20 ENTR to start the Universal Tracking and Rendezvous Navigation Program (P20). Upon the FL VERB 04 NOUN 06 display, key VERB 22 ENTR and load 00002 (Option Code 2) into register R2.
7. When the desired option code is being displayed, key PRO and observe that the display changes to FL VERB 06 NOUN 78. Key VERB 24 ENTR and load R1 and R2 with the desired body-axis of rotation—GAMMA, RHO. (See paragraph 4.2.1.)
8. When the desired rotation-axis parameters are being displayed, key PRO and observe that the display changes to FL VERB 06 NOUN 79. Key VERB 24 ENTR and load R1 and R2 with the desired rotation rate and deadband. (R2 is preloaded with last R03 deadband. When R2 contains zero, minimum deadband, 0.5 deg, is used.)
9. When the desired rate and deadband are being displayed, key PRO and observe that the display changes to FL VERB 06 NOUN 34. Key VERB 25 ENTR and load R1, R2, and R3 with the desired GET for starting the attitude maneuver (Maneuver GET computed from Figure 4.2.6-5). Key PRO when desired GET is being displayed.

   NOTE.—If the time loaded is in the past, rotation begins upon crew's PRO. Otherwise, rotation about the axis specified in NOUN 78 begins at the time specified in NOUN 34. (P20, Option-2-compatible program active, with no intervening "permanent" termination of P20. Refer to paragraph 4.2.1, Figure 4.2.1-1.)

B. Rate-aided Tracking

1. With P20 (Option 2) set up to initiate a controlled-rate attitude maneuver at the appropriate time, key VERB 37 ENTR 24 ENTR to start the Rate-aided Optics Program (P24). Upon the FL VERB 06 NOUN 89 display—
   a) Set OPTICS ZERO switch to OFF
   b) Set OPTICS SPEED switch to HI
   c) Verify OPTICS MODE switch in CMC
   d) Verify SC CONT switch in CMC
   e) Verify CMC MODE switch in AUTO
   f) Key VERB 25 ENTR and load the landmark latitude, longitude/2, and altitude into NOUN 89 (R1, R2, R3)

   NOTE 1.—Unless OPTICS ZERO switch set to OFF at this point, PRO sends program directly to FL VERB 51. VERB 16 NOUN 92 display of optics shaft and trunnion angles would have to be called manually.

   NOTE 2.—If OPTICS MODE switch is in MAN at this point, PRO sends program directly to FL VERB 51. Display of optics shaft and trunnion angles would require manual VERB 16 NOUN 92 ENTR.

   g) PRO

2. Monitor shaft and trunnion angles (nonflashing VERB 06 NOUN 92). If trunnion angle required to acquire the landmark is greater than 90 deg, an alarm 00404 will occur. This would indicate an anomalous condition, probably requiring that the pass be aborted. Possible causes would be (a) initial tracking attitude not achieved, (b) bad landmark coordinates, (c) premature initiation of pitch rate, (d) bad state vector, (e) bad REFSMMAT.
3. When landmark becomes visible in the SCT, turn the OPTICS MODE switch to MAN, and observe a flashing VERB 51, "Please mark," on the DSKY. Use optics handcontroller to center landmark in crosshairs. Take marks as required by Mission Planning.

C. Post-tracking

1. At the completion of the pass, key VERB 37 ENTR 00 ENTR to call the CMC Idling Program (P00), terminating P24 activity. Turn the OPTICS MODE switch to CMC and the OPTICS ZERO switch to ZERO.

TABLE 4.2.6-1

RATE-AIDED OPTICS (CSM P24) DSKY PROCEDURES (SHEET 1 OF 3)

No.	Entry Point	Display	PROG	Purpose	Register	CMC Operation	Crew Action	Remarks
A-1	P00 (VERB 37 ENTR 00 ENTR)	---	00	Establish initial conditions preceding start of tracking sequence	---	Perform state-vector extrapolation	Set SC CONT switch to CMC Set CMC MODE switch to AUTO Set OPTICS MODE switch to CMC Key VERB 49 ENTR to call Crew-defined Maneuver Routine (R62).	TCA -10 minutes (approximately).
A-2	R62 (VERB 49 ENTR)	FL V06 N22	00	Request crew to specify a rotational maneuver to landmark acquisition attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, call Attitude Maneuver Routine (R60).	PRO, or key VERB 25 ENTR to load new gimbal angles; then PRO.	
A-3	---	FL V50 N18 (R60)	00	Request automatic attitude maneuver to landmark acquisition attitude.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, perform attitude maneuver.	PRO	
A-4	---	V06 N18 (R60)	00	Nonflashing display of final gimbal angles as maneuver is being performed.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Perform maneuver calculation and ICDU drive to achieve final gimbal angles.	Monitor FDAI Ball and Attitude Error Needles; if maneuver approaches gimbal lock, use RHC to avoid and complete the maneuver manually Observe that the nonflashing V06 N18 returns to FL V50 N18 when maneuver finishes.	Maneuver rate will be as prescribed by the DAP Data Load Routine (R03), when last performed. Any RHC input terminates automatic maneuver and returns to flashing V50 N18. If MGA reaches ±75 deg, maneuver terminates and must be completed manually.
A-5	---	FL V50 N18 (R60)	00	Request maneuver to trim attitude within RCS DAP deadband limits.	R1 xxx.xx deg OGA R2 xxx.xx deg IGA R3 xxx.xx deg MGA	Upon crew's PRO, recycle attitude maneuver Upon crew's ENTR, exit R60/R62	If displayed gimbal angles and present attitude do not agree within deadband limits, key PRO or use RHC to trim. When displayed gimbal angles and present attitude agree within deadband limits, key ENTR.	PRO causes nonflashing V06 N18 display to return until trim maneuver has completed; then, FL V50 N18 returns. PRO again repeats the sequence; ENTR terminates R60/R62.

TABLE 4.2.6-1

RATE-AIDED OPTICS (CSM P24) DSKY PROCEDURES (SHEET 2 OF 3)

No.	Entry Point	Display	PROG	Purpose	Register	CMC Operation	Crew Action	Remarks
A-6	P20 (VERB 37 ENTR 20 ENTR)	FL V04 N06	20	Display option code (zero pre-loaded).	R1 00024 Checklist code R2 oooox Option code (x = 0, 1, 2, 4, 5)	Accept new data Upon crew's PRO, proceed to next step.	Load R2 with 00002 PRO	See paragraph 4.2.1 for description of P20.
A-7	---	FL V06 N78	20	Display pointing-vector angles describing body axis that the controlled-rate attitude maneuver shall be executed about.	R1 ± xxx.xx deg (γ) R2 ± xxx.xx deg (ρ) R3 ± xxx.xx deg (OMICRON) (OMICRON not relevant to this option).	Accept new data Upon crew's PRO, proceed to next step.	Load R1 and R2 with desired angles PRO	---
A-8	---	FL V06 N79	20	Display rotation rate and deadband.	R1 ± x.xxxx deg/sec rate R2 + xxx.xx deg (deadband) R3 Blank (R2 preloaded with last R03 deadband. When R2 contains zero, minimum deadband, 0.5 deg, used.)	Accept new data Upon crew's PRO, proceed to next step.	Load new data PRO	---
A-9	---	FL V06 N34	20	Display time to begin controlled-rate attitude maneuver.	R1 + ooxxx hr(GET) R2 + oooxx min R3 + oxx.xx sec	Accept new data Upon crew's PRO, wait until time of rotation* and then begin controlled-rate attitude maneuver. Continue P20 in background when P24 is called.	Load desired time of maneuver (pad). PRO Call P24.	*NOTE. —If the time loaded is in the past, rotation begins immediately. Otherwise, rotation about the vector specified in NOUN 78 begins at the time specified in NOUN 34. (P20, Option-2-compatible program active, with no intervening "permanent" termination of P20. Refer to paragraph 4.2.1, Figure 4.2.1-1.)
B-1	P24 (VERB 37 ENTR 24 ENTR)	FL V06 N89	24	Display landmark data.	R1 xx.xxx deg Lat ("+" = North) R2 xx.xxx deg LONG/2 ("+" = East) R3 xxx.xx n.mi. Altitude	Start rate-aided optics program. Extrapolate state vector to present. Accept data Upon crew's PRO, proceed to next step.	Set OPTICS ZERO switch to OFF. Set OPTICS SPEED switch to HI. Verify OPTICS MODE switch in CMC. Verify SC CONT switch in CMC. Verify CMC MODE switch in AUTO. Load desired landmark data. PRO	NOTE 1. —Unless OPTICS ZERO switch set to OFF at this point, PRO sends program directly to FL VERB 51. NOTE 2. —If OPTICS MODE switch is in MAN at this point, PRO sends program directly to FL VERB 51.

TABLE 4.2.6-I

RATE-AIDED OPTICS (CSM P24) DSKY PROCEDURES (SHEET 3 OF 3)

No.	Entry Point	Display	PROG	Purpose	Register	CMC Operation	Crew Action	Remarks
B-2	---	V06 N92 (R52)	24	Display optics shaft and trunnion angles	R1 xxx.xx deg shaft R2 xx.xxx deg trunnion R3 Blank	Extrapolate CSM state-vector to present time +1.9 sec Get IMU orientation from storage Read vehicle attitude from ICDUs Get landmark coordinates from storage Compute target vector from CSM to landmark Compute the required optics angles to point LOS along target vector [Display Alarm 404 if required trunnion angle is greater than 90 deg] Drive shaft and trunnion CDUs Upon crew's setting OPTICS MODE switch to MAN, call the Sighting Mark Routine (R53) and continue to recycle until terminated by R53.	Monitor shaft and trunnion angles, and look for landmark in optics. When landmark is visible in optics, set OPTICS MODE switch to MAN to call R53.	If CSM has been maneuvered to the initial-acquisition attitude, and if the controlled-rate pitch maneuver is initiated at the proper time, an alarm 404 is unlikely since it would mean a large discrepancy in the REFSMMAT, the state vector, or the landmark coordinates.
B-3	---	FL V51 (R53)	24	Request marks be taken at will.	R1 Blank R2 Blank R3 Blank	At prescribed time, initiate controlled pitch rate Compute new landmark coordinates from latest mark data Compute shaft and trunnion rates and drive shaft and trunnion CDUs. Downlink mark data in real time	Center target in cross-hairs and depress MARK button at will and according to mission plan If a mark is judged unsatisfactory, depress MARK REJ button and repeat mark When finished with sightings, key PRO to terminate R53/R52; Key 00 ENTR to terminate P20/P24.	Crew can terminate rate-aided optics feature and continue with manual tracking by returning OPTICS MODE switch to CMC.
C	P00 (VERB 37 ENTR 00 ENTR)	---	00	Maintain CMC in idle state.	---	Perform state vector extrapolation	Set OPTICS MODE switch to CMC Set OPTICS ZERO switch to ZERO	

4.2.6.5 Restrictions and Limitations

In addition to the 90-deg limitation on the optics cone of acquisition (see paragraph 4.2.6.2), the Rate-aided Optics Program is further limited by maximum tracking rate and by the visual limitations of the optics. Maximum tracking rate is the crucial factor in determining spacecraft pitch rate and how close the shaft axis can be to the tracking plane. The optimum condition at minimum altitude is to have the spacecraft pitching at 2 deg/sec and the optics shaft axis directed approximately 20 deg out of the tracking plane. It is also desirable that the simultaneous occurrence of maximum shaft rate and maximum LOS rate be avoided. (See paragraph 4.2.6.2.)

The visual limitations of the optics determine both the maximum altitude the program can be used effectively and the choice of optical device—SXT or SCT. At maximum altitudes, the sextant's magnification capability becomes critical; at minimum altitude, the scanning telescope's wider field of view is the decisive factor. Between these extremes, the choice should favor the higher magnification—for better marks—whenever the SXT's field of view is adequate for acquisition.

An intrinsic limitation of the Rate-aided Optics Program is that it does not relieve from the astronaut the task of actually centering and tracking the target. If tracking with the optics handcontroller is interrupted, the target should remain in the vicinity of the crosshairs, but manual recentering is required before another mark is taken.

4.2.6.6 Coordination Procedures

The assumptions associated with the Rate-aided Optics Program are as follows:

1. A recognizable feature, whose approximate position on the lunar surface is known, can be visually identified.
2. The IMU is on and aligned to a known reference.
3. The computer and optical subsystems are operational.
4. Telemetry contact can be effected between the CSM and the ground.

Depending upon which is known more accurately—the surface feature's location or the spacecraft's orbit—telemetered measurement data are used by the ground to refine its knowledge either of the orbit or the target. Typically, the IMU Realignment Program (P52) will have been performed to align the CSM stable member to the landing-site REFSMMAT—Option 1. (The alignment programs are described in Section 7.0.) Also, the Digital Autopilot Data Load Routine (R03) will have been performed for the current vehicle configuration. (R03 is described in paragraph

9.2.1.) Input data will have been provided for the following, either as advance pad or through the CMC Update Program (P27, paragraph 4.2.5):

a. Landmark coordinates and altitude
b. CSM Preliminary Attitude
c. Pitch-initiation time
d. Rotation rate, deadband, and axis of rotation
e. Mark-initiation time
f. Time of closest approach

As marks are taken, the measurement data are down-linked automatically, in real time. To avoid the possibility of lost data, however, the crew can turn on the onboard recorder before beginning the tracking sequence. After the tracking sequence has been completed, the CMC Update Program (P27) can be called, and the ground-computed results uplinked to the computer. If the precise location of the LM landing site is the variable selected for update, subsequent performance of the IMU Realignment Program (P52)—Option 1—incorporates the new data in order to refine the CSM stable-member orientation with respect to landing-site local vertical.

4.2.6.7 Alarms

Observing a PROG alarm light, the crew keys VERB 05 NOUN 09 ENTR for a display of the alarm code, unless the code has been displayed automatically. After taking corrective action, the crew keys RSET to clear the alarm and continues with the program. Alarm possibilities during P24 are as follows:

a. Alarm 00110 indicates that the crew depressed the MARK REJECT button unnecessarily— no marks to reject. Key RSET to extinguish the PROG light and continue normal operation.
b. Alarm 00116 indicates the optics were switched to OFF from ZERO before the 15 sec optics zeroing time had elapsed. Set the OPTICS ZERO switch to ZERO, key RSET, wait 15 sec, and continue normal operation.
c. Alarm 00120 indicates optics not zeroed at the time of an optics torque request. Set OPTICS ZERO switch to OFF, then to ZERO. Key RSET and wait 15 sec before continuing.normal operation.
d. Alarm 00210 indicates IMU not operating. It should be turned on and the stable member orientation determined before starting tracking sequence.

e. Alarm 00220 indicates IMU not aligned. No REFSMMAT is stored. Key RSET, and perform P51.

f. Alarm 00401 indicates desired angles yield gimbal lock. Key RSET, and either select new gimbal angles or maneuver spacecraft to avoid gimbal lock.

g. Alarm 00404 indicates optics cannot acquire the target selected (required trunnion angle greater than 90 deg). Perform one of the following, and key RSET: (a) manually maneuver spacecraft until optics can acquire target, and key PRO; (b) key VERB 34 ENTR to terminate auto optics positioning routine.

4.2.6.8 Restarts

P24 is restart protected.

4.2.7 P29, Time of Longitude—CMC

The Time of Longitude Program is used to compute and display the ground-elapsed time at which the LM or CSM will pass over a crew-specified longitude. The crew can choose to have the CMC compute time of longitude for either the LM or the CSM. Program calculations are then made based on the assumption that the chosen vehicle remains in free fall from the selected start time (base time) until the time of crossing. The program can be used while the CSM is in earth or in lunar orbit. It is most likely to be used in lunar orbit, however, since the CSM does not remain in earth orbit long enough to make P29 use practicable.

In addition to displaying the time of crossing over the specified longitude, P29 computes and displays the latitude and vehicle altitude at the point of crossing. Significantly, the time (and related data) displayed by P29 is the time of the first crossing of the vehicle over the crew-specified longitude after the crew-selected base time. Generally, the crew selects present time (all zeros in the VERB 06 NOUN 34 display) as base time, but can also select any past or future time. In all cases of P29 use, the base time should be carefully selected to allow optimum sequencing and performance of desired tasks.

4.2.7.1 Program Use

Because the information displayed by P29 is nominally uplinked from ground, the program is most useful in case of communication loss with ground. It can also prove useful to the crew for sighting either scheduled or unscheduled landmarks for tracking and photography, and for obtaining ground-track information for the landing site.* P29 can be entered after the lunar-orbit injection burn, for example, to determine exact time of CSM passage—on the first pass—over the landing site. P29 can also be entered before P24, the Rate-aided Optics Tracking Program, to give the crew the time-of-closest approach (TCA) on that orbit for P24.

---

*P29 can be used with options 0, 1, 2, 4, and 5 of P20 running in the background for tracking only—no navigation.

4.2.7.2 Program Summary

Upon keying VERB 37 ENTR 29 ENTR, the crew observes flashing VERB 04 NOUN 06 with R2 containing the CMC-assumed option code, 00001. If the crew desires the time of longitude and related P29-displayed data for the LM, he keys VERB 22 ENTR and loads R2 with option code 00002. Otherwise, he keys PRO and observes flashing VERB 06 NOUN 34, displaying the ground-elapsed base time in hours, minutes, and seconds. This display is the base time from which the next crossing of the desired longitude is computed. The choice of base time, is, therefore, crucial to the effective use of P29. The registers initially contain all zeros indicating present time. To select another base time, the crew keys VERB 25 ENTR, loads the desired time, and upon its display, keys PRO. If the present time is satisfactory, he merely keys PRO and observes the flashing VERB 06 NOUN 43 requesting entry of the desired longitude. To load the longitude for which GET is computed, the crew keys VERB 22 ENTR and loads longitude. The CMC then computes GET for the next crossing of this longitude and displays it in flashing VERB 06 NOUN 34. To respecify the longitude using the base time originally entered, the crew keys VERB 32 ENTR. The CMC recycles the program to the flashing VERB 06 NOUN 43 display allowing the crew to change desired longitude. If the GET displayed is satisfactory, the crew keys PRO and observes flashing VERB 06 NOUN 43, the latitude, longitude and vehicle altitude at the point of crossing. If the data in NOUN 43 is satisfactory, the crew keys PRO, which terminates P29 and allows selection of a new program via VERB 37. The crew can also respecify all the input data by keying VERB 32 ENTR and causing the program to recycle to the flashing VERB 04 NOUN 06 display.

4.2.7.3 Procedures

1. Key VERB 37 ENTR 29 ENTR
   - Observe display of option code:

     FL VERB 04 NOUN 06

     R1 00002 specify vehicle
     R2 0000x option code
     R3 Blank

     NOTE: The CMC assumes option code 00001 indicating the CSM. To specify LM, use option code 00002.

- Key VERB 22 ENTR to load desired option code in R2.
- PRO

2. Observe flashing display of ground-elapsed base time from which next crossing of desired longitude is computed:

   - <u>FL VERB 06 NOUN 34</u>

     R1 00xxx. hr
     R2 000xx. min.
     R3 0xx. xx sec

   <u>NOTE</u>: Initial display contains all zeros indicating present time. Unless crew changes this display, P29 will base its calculations on the present time.

   - Key VERB 25 ENTR to load desired base time.
   - PRO

   <u>NOTE:</u> The CMC integrates the state vector forward or backward to the desired base time specified by the crew.

3. Observe flashing display of desired longitude:

   - <u>FL VERB 06 NOUN 43</u>

     R1 Blank
     R2 xxx. xx deg Long
     R3 Blank

   <u>NOTE:</u> The desired longitude is specified positive eastward and negative westward for both earth and moon.

   - Key VERB 22 ENTR to load desired longitude.
   - PRO.

   <u>NOTE</u>: Upon a <u>PRO</u> the CMC computes the time of the <u>first</u> crossing over the longitude specified in Step 3 <u>after</u> the base time specified in Step 2.

4. Observe flashing display of the CMC-computed time of longitude crossing:

   - <u>FL VERB 06 NOUN 34</u>

     R1 00xxx. hr
     R2 000xx. min
     R3 0xx. xx sec

- Key VERB 32 ENTR to respecify longitude using base time already specified in Step 2.
- PRO

  NOTE: A recycle (VERB 32 ENTR) returns the program to Step 3.

5. Observe flashing display of latitude, longitude, and altitude at crossing:

   FL VERB 06 NOUN 43

   R1 xxx. xx deg Lat (+North)
   R2 xxx. xx deg Long (+East)
   R3 xxxx. x n. mi Alt

- Key VERB 32 ENTR (recycle) to respecify input data by returning to FL V04 N06.
- PRO

  NOTE: A PRO response terminates P29.

6. Observe flashing display of request for new program:

   FL VERB 37

- Key xx ENTR.

4.2.8 P79, Final Rendezvous Program—CMC

P79 is used following P35 to initiate tracking of the LM with the X-axis of the CSM, and then to initiate R31 to display range, range rate, and theta. For details see Part V (Final Phase) of paragraph 4.2.1.2.2.2, and paragraph 4.2.1.2.6.

Blank

SUBSECTION 4.3

LGC COASTING FLIGHT NAVIGATION PROGRAMS

B L A N K

4.3.1 P20, Rendezvous Navigation—LGC

The Rendezvous Navigation Program, P20, controls the LM attitude and the rendezvous radar (RR) to acquire and track the CSM with the RR during rendezvous. The program processes RR tracking data to permit updates of either the LM or the CSM state vector maintained in the LM Guidance Computer (LGC). P20 can also track the CSM with the RR without updating either state vector, for example after DOI, when the RR may be used to track the CSM without updating as an abort contingency measure. P20 control of the LM attitude also points the LM optical beacon at the CSM. When the RR is read by P20, RR mark data are automatically transferred to the AGS via downlink.

Radar-range, range-rate, and tracking-angle data are used by the LGC to update the state vector of the active vehicle relative to the passive vehicle. P20 maintains estimates of the LM and CSM state vectors during the navigation portion of each rendezvous phase: CSI, CDH, TPI, and TPM. Based on the updated estimates thus obtained, the appropriate targeting program (P32, P33, P34, P35 respectively) computes the Δv required to effect each rendezvous maneuver in turn.

Figure 4.3.1-1 is a simplified functional diagram of the rendezvous-navigation logic used in the LGC. Normally, the LM is the active vehicle, and the CSM is the passive vehicle.

Extrapolating both state vectors to the time of measurement, P20 computes an estimate of one of the parameters the RR measures (e.g., range) ($\hat{Q}$), which is compared with the measured range (Q) to obtain a measurement deviation δQ. This is multiplied by a statistical weighting vector ($\underline{\omega}$), which is computed from an onboard statistical estimate of (1) state-vector uncertainties (W-matrix), (2) radar range measurement error (α^2), and (3) a measurement geometry vector ($\underline{b}$). The resulting $\delta \underline{x}$ is a statistically optimum linear estimate of deviation to be added to the current estimate of the state vector to be updated. The same procedure is carried out for the other radar parameters (range rate and two tracking angles).

4.3.1.1 Program Options

A fundamental P20 option is whether to update the CSM state vector or the LM state vector. Considerations affecting the decision are (1) the desire to update the state vector having the larger uncertainties, and (2) the desire to update the state vector of the vehicle that is to perform the rendezvous maneuvers. Almost always, both considerations will favor updating the LM since the CSM state will have benefited

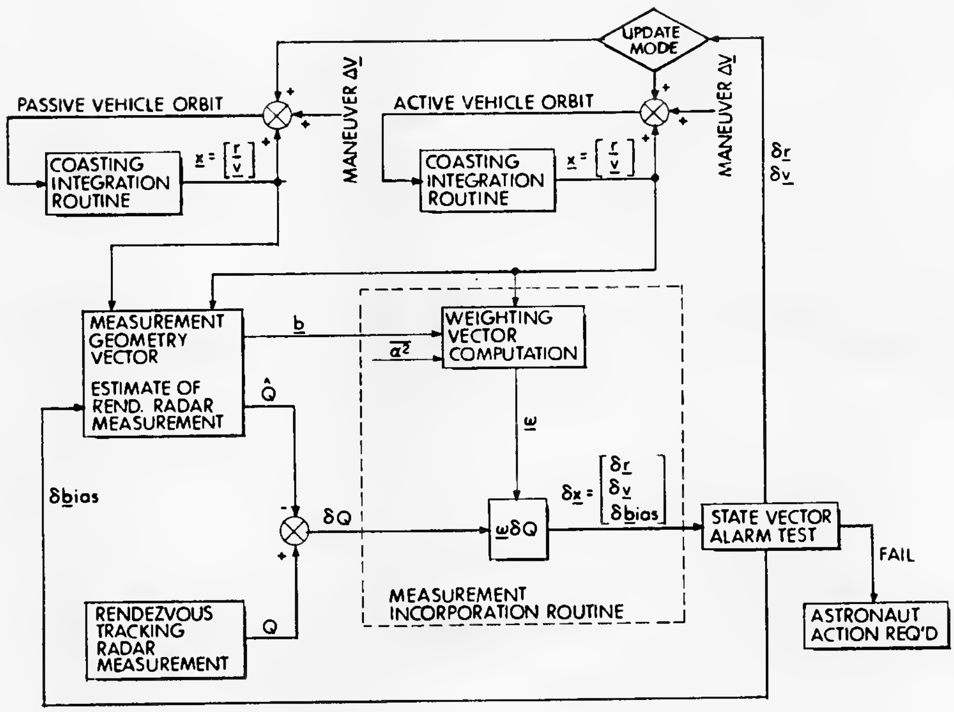


Figure 4.3.1-1. Simplified Rendezvous Navigation Diagram (LM)

from MSFN tracking prior to, and during, the ascent, while the LM state is degraded by maneuver uncertainties. Should the LM state-vector uncertainty be smaller, however, updating the CSM would be preferred. The state vector to be updated can be changed at any time during P20 operation by keying in VERB 80 ENTR (LM update), VERB 81 ENTR (CSM update), or VERB 95 ENTR (no-update mode).

NOTE: After VERB 95 ENTR is keyed in to prevent updating either state vector, VERB 80 ENTR or VERB 81 ENTR must be keyed to allow state-vector updating; reselection of P20 will not automatically cause state-vector updating to resume.

Another option is the choice between manual or automatic acquisition of the CSM by the LM RR. Normally, the RR mode select switch is put in the LGC position for automatic target acquisition when the astronaut turns on the RR heaters before entering P20. The astronaut may elect to use the manual mode (SLEW switch position), however, for acquisition. If he does, he places the mode control switch in the SLEW position before entering P20. R23 is used to perform the manual acquisition. (Note, however, that R23 can be performed only if P20 is the only program running.)

4.3.1.2 Procedures

The procedures employed in the operation of P20 are discussed in this paragraph; the routines involved in its operation, and referenced herein, are discussed in detail in numerical order in paragraph 4.3.1.4. Figure 4.3.1-2 charts the logical flow of P20; Table 4.3.1-I summarizes P20 verbs and displays, and Table 4.3.1-II gives the extended verbs.

The IMU Orientation Determination Program (P51) or the Lunar Surface Alignment Program (P57) should be completed before the selection of P20. If this is not done, the LGC may not have a satisfactory inertial reference and a program alarm will occur. Both the LM and CSM must maneuver to their respective preferred tracking attitudes, which correctly orient the LM RR and CSM radar transponder before RR tracking, using P20, is initiated by the LM. For both vehicles, P20 maintains the preferred tracking attitude automatically once it is achieved; radar track is broken, however, each time a maneuver to a burn attitude is necessary. The rendezvous radar must be on and warmed up to operating condition, and preliminary checkout should be completed via R04 (see paragraph 4.3.1.4) before entering P20. Before entering P20, the astronaut places the RR mode control switch (1753 on the RADAR panel) in the LGC position, unless he wishes to manually acquire the CSM as discussed in paragraph 4.3.1.1. If P20 is selected before the powered descent in the lunar mission, P20 must be entered and operated in the no-update mode; i.e., VERB 95 ENTR must be keyed in prior to selecting P20.

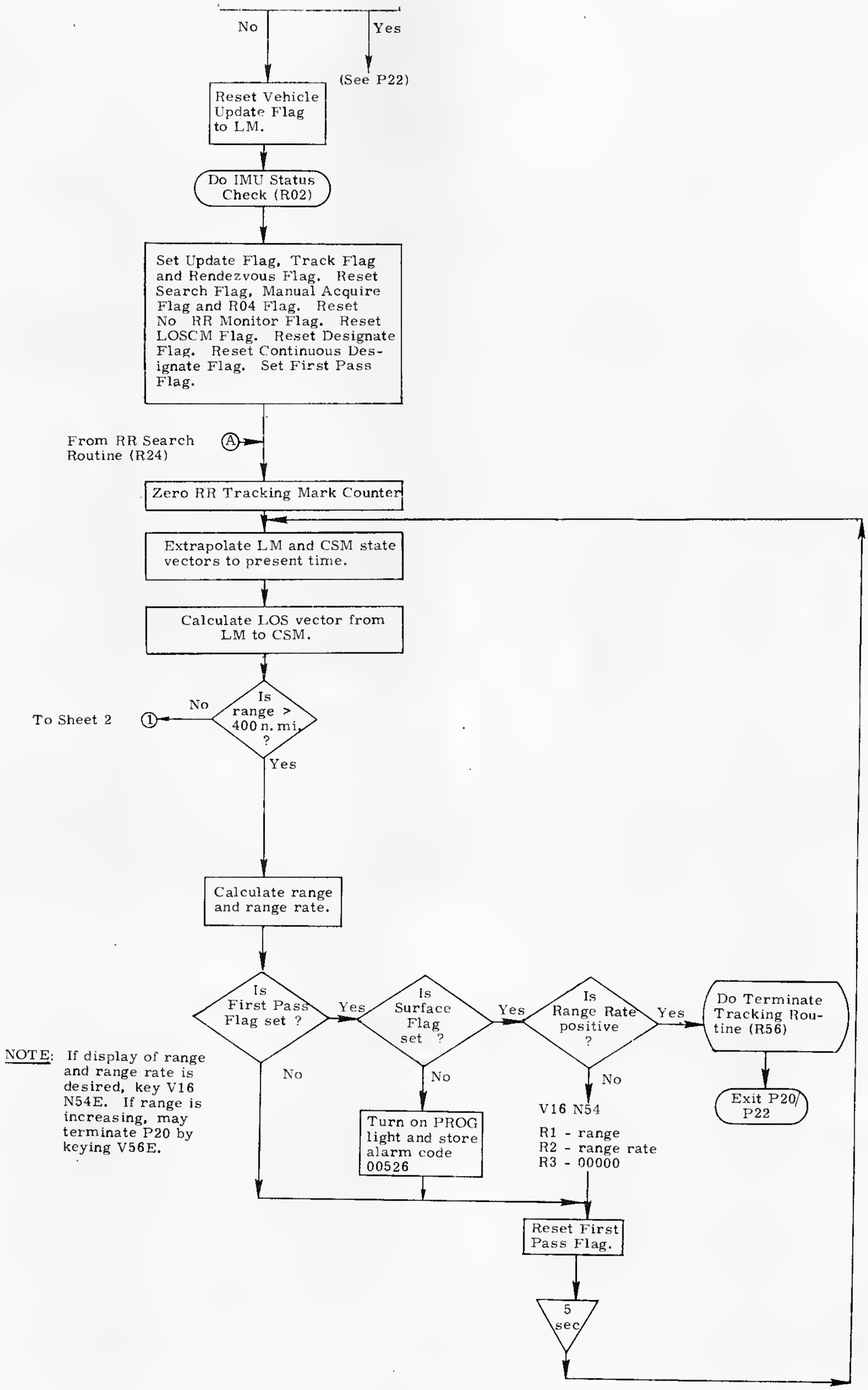


Figure 4.3.1-2. Rendezvous Navigation Program (LM P20) (Sheet 1 of 3)

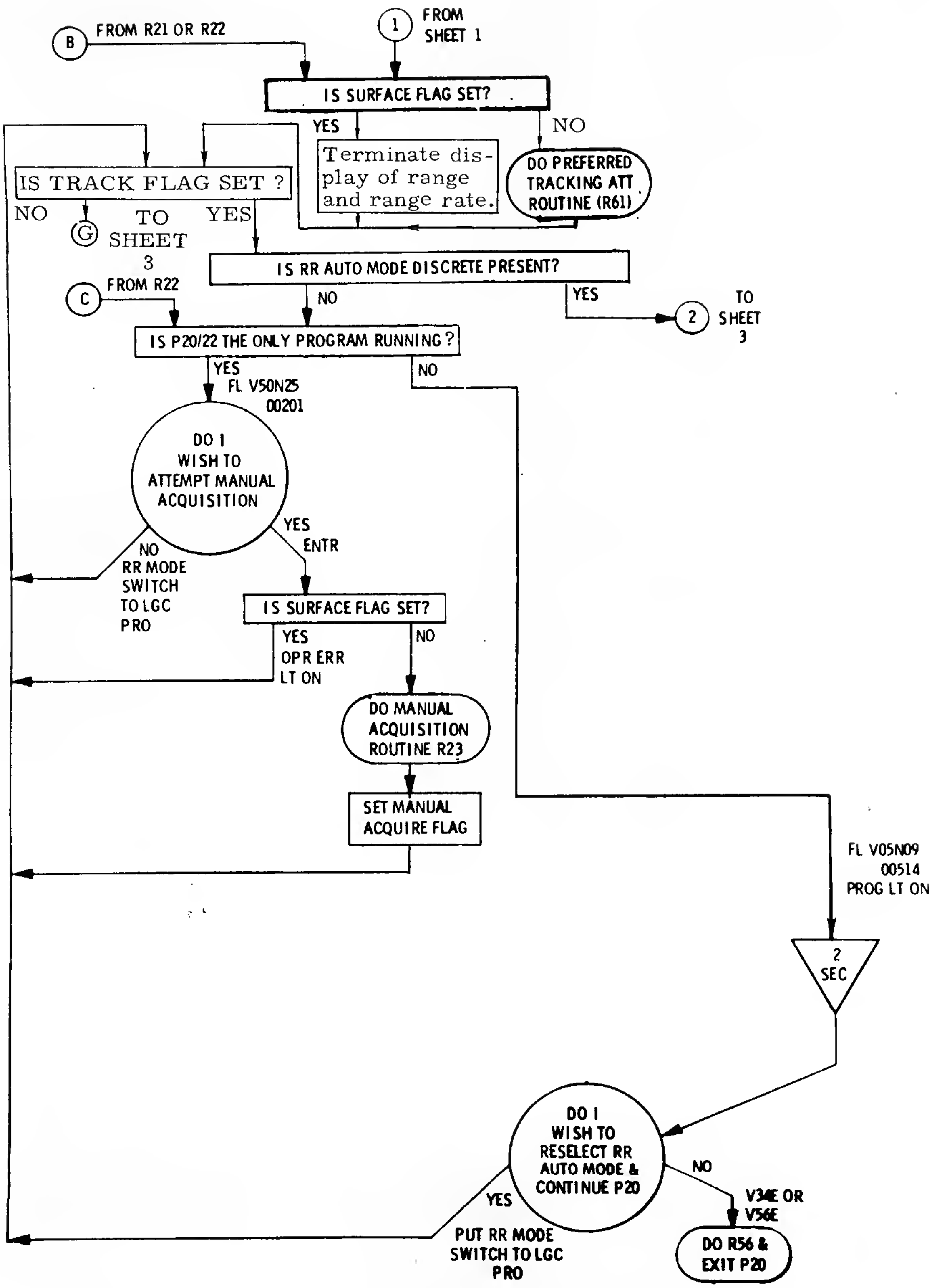


Figure 4.3.1-2. Rendezvous Navigation Program (LM P20) (Sheet 2 of 3)

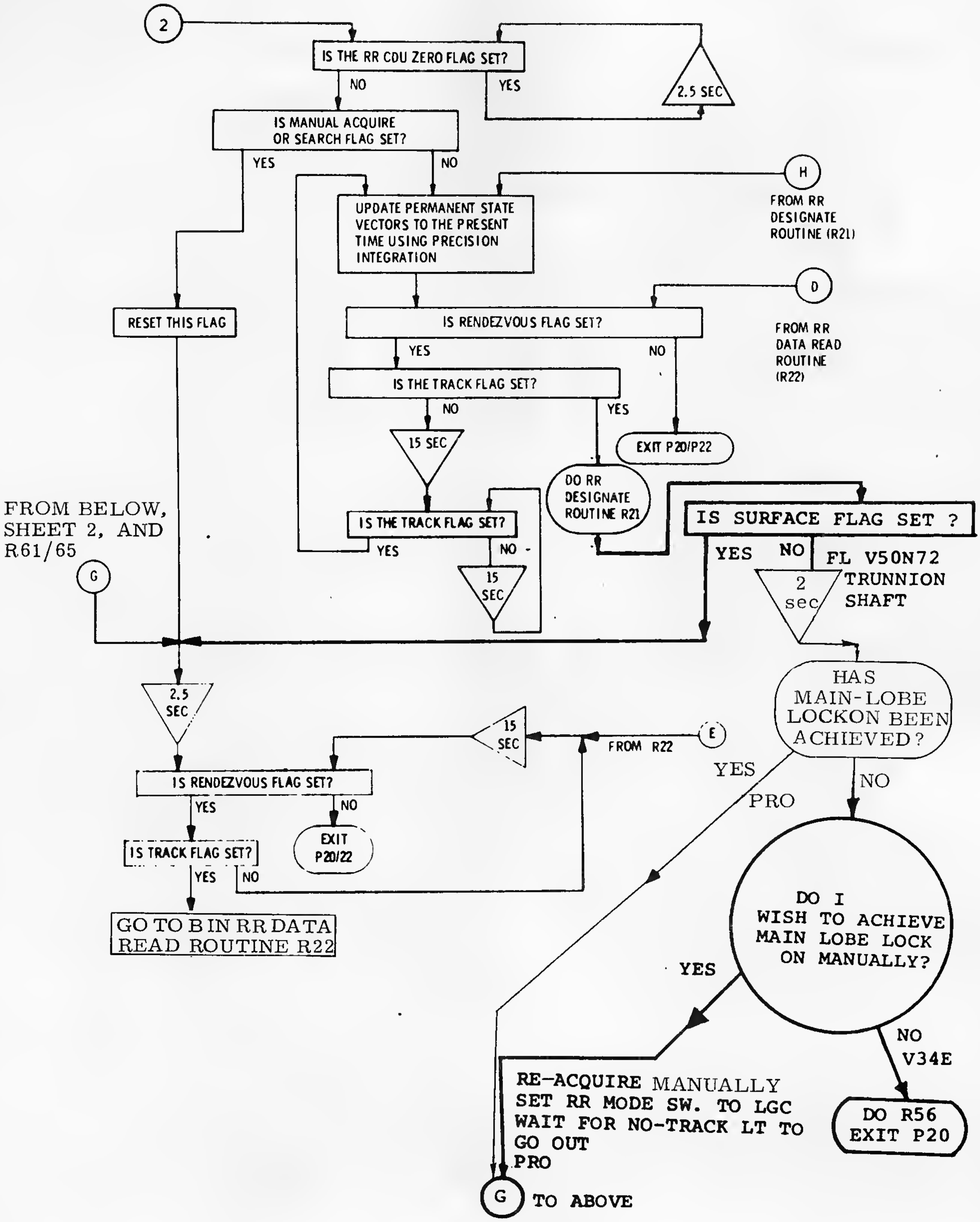


Figure 4.3.1-2. Rendezvous Navigation Program (LM P20) (Sheet 3 of 3)

TABLE 4.3.1-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH RENDEZVOUS NAVIGATION (LM P20) (SHEET 1 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
FL V37	R00	Request astronaut to select another program	- - -	R1 xxxxx R2 xxxxx R3 xxxxx
V05 N09E	Astronaut (R02)	Verify PROG alarm	00210 = IMU not operating	R1, R2, R3 xxxxx*
V05 N09E	Astronaut (R02)	Verify PROG alarm	00220 = IMU not aligned	R1, R2, R3 xxxxx*
FL V04 N12	R04	Display option code for assumed radar	R1 = option code for assumed radar R2 = LGC option code 00001 = RR 00002 = LR	R1 00004 R2 oooox R3 Blank
V22 E	Astronaut (R04)	Load desired radar code in R2	- - -	- - -
FL V50 N25	R04 and P20	Request astronaut to select RR auto mode	- - -	R1 00201 R2 Blank R3 Blank
FL V16 N72	R04	Display RR CDU angles	R1 = Trunnion angle, 360 minus RR CDU value R2 = RR shaft angle	R1 xxx.xx deg R2 xxx.xx deg
FL V50 N72	P20	Priority display RR CDU angles	R1 = Trunnion angle, 360 minus RR CDU value R2 = RR shaft angle	R1 xxx.xx deg R2 xxx.xx deg
FL V16 N78	R04	Display RR range, range rate, and TFI Note: The value displayed for TFI is not meaningful in R04 unless it is being computed by some other program.	Range Range Rate TFI = time from t_{IG} in min and sec to nearest sec. Max reading is 59B59. (-before, + after t_{IG}, B = Blank).	R1 xxx.xx n.mi. R2 xxxx.x fps R3 xxBxx min, sec

* Refer to note in paragraph 3.3.1.6.

TABLE 4.3.1-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH RENDEZVOUS NAVIGATION (LM P20) (SHEET 2 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
FL V05 N09	R21	PROG alarm Priority display	00503 = R21 unable to acquire CSM (displayed in R1, R2, or R3 depending on presence or absence of other alarm codes)	R1 xxxxx R2 xxxxx R3 xxxxx
FL V50 N25	R23	Request astronaut to perform manual acquisition of CSM		R1 00205 R2 Blank R3 Blank
FL V05 N09	R22	PROG alarm Priority display	00525 = Delta theta greater than 3 deg (displayed in R1, R2, or R3 depending on presence or absence of other alarm codes)	R1 xxxxx R2 xxxxx R3 xxxxx
FL V06 N05	R22	Priority display delta theta		R1 xxx. xx deg R2 Blank R3 Blank
FL V06 N49	R22	Priority display excessive update parameters NOTE: Displays automatically. If astronaut calls up this display himself, he can get a display of his parameters if he does it right after a mark. In this case, it would not be a display of "excessive" updates.	R1 = Delta r; magnitude of difference between position state vector before and after incorporation of mark data R2 = Delta v; magnitude of difference between velocity state vector before and after incorporation of mark data NOTE: Both parameters not necessarily excessive Source code; Error source code causing this display where R3 = oooox x = 1 RR range x = 2 RR range rate x = 3 RR shaft angle x = 4 RR trunnion angle	R1 xxx. xx n. mi. R2 xxxx. x fps R3 xxxxx

TABLE 4.3.1-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH RENDEZVOUS NAVIGATION (LM P20) (SHEET 3 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
FL V06 N49 (Cont.)			Source code indicates which measurement parameter (range, range rate, shaft angle, trunnion angle) is responsible for excessive update.	
FL V06 N99	V67E	Display RSS position, velocity, and angle bias errors of W-matrix	R1 = RSS position error R2 = RSS velocity error R3 = RSS bias error	R1 xxxxx. ft R2 xxxx.x fps R3 xxxxx. m rad
FL V05 N09	R23	To indicate if CSM presently outside allowable limits of present RR antenna mode	Alarm code 00501	R1 xxxxx R2 xxxxx R3 xxxxx
FL V16 N80	R24	Priority display of RR search parameters; indicates LGC-controlled search pattern in process*	R1 initially = 00000. If search is successful (RR data good discrete received) R1 = 11111. R2 initially = 00000. When RR designation begins, R2 = Omega (angle between RR LOS and LM+Z-axis)	R1 xxxxx R2 xxx.xx deg R3 Blank
V05 N09E	Astronaut (R25)	Verify PROG alarm	00515 identifies RR CDU failure	R1 xxxxx R2 xxxxx R3 xxxxx

For an explanation of P20-generated priority display considerations when P20 is running in the background of a targeting program, refer to paragraph 4.3.1.7.

TABLE 4.3.1-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH RENDEZVOUS NAVIGATION (LM P20) (SHEET 4 OF 4)

DSKY	Initiated by	Purpose	Condition	Register
FL V50 N18	R60	Priority astronaut request to perform auto maneuver and display final FDAI ball angles*	Final FDAI ball angles, R1 = Roll; R2 = Pitch; R3 = Yaw; NOTE: If final FDAI ball angles computed result in ± 90 deg, yaw, transformation from IMU to FDAI in roll and pitch indeterminate; R1 and R2 will be set to 0. If yaw angles near ± 90 deg, values of R1 and R2 may not be reliable	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
FL V16 N56	V85E	To display RR antenna azimuth and elevation	R1 = RR LOS azimuth R2 = RR LOS elevation	R1 xxx.xx deg R2 xxx.xx deg R3 Blank

*If R60 called by R61 or R65.

TABLE 4.3.1-II

EXTENDED VERBS USED WITH RENDEZVOUS NAVIGATION (LM P20)

VERB	Identification	Purpose and Remarks
40 N72 ENTR	RR CDU Zero	Used to zero the RR CDUs. Selected by DSKY entry at any time.
44 ENTR	Terminate RR Continuous Designate	Used to terminate continuous designate option of 41 N72. Selected by DSKY entry.
60 ENTR	Display vehicle attitude rates.	Displays on the FDAI error needles the PGNCS— derived vehicle attitude rates.
61 ENTR	Display DAP attitude error	Displays on the FDAI Error Needles the difference between the current CDU angles and the DAP commanded angles.
62 ENTR	Display total attitude error	Displays the total attitude error which is the desired CDU angles minus the present CDU angles.
63 ENTR	Call RR/LR Self-Test Routine, R04	Displays RR/LR information during self-test.
67 ENTR	W-Matrix RSS error display	Provides a means of displaying W-matrix RSS position, velocity, and bias errors which can be overwritten if reinitialization is desired. Reinitialization zeros off-diagonal (correlation) terms. Terminate via V34E.
80 ENTR	Enable LM state vector update	Causes the rendezvous data processing results to update the LM state vector.
81 ENTR	Enable CSM state vector update	Causes the rendezvous data processing results to update the CSM state vector.
85 ENTR	Display RR LOS azimuth and elevation	Provides for the display of the RR antenna azimuth and elevation.
93 ENTR	Enable W-matrix initialization	Permits the crew to reinitialize W-matrix. This is accomplished by resetting the RENDWFLG. This flag reset indicates a W-matrix is invalid and is reinitialized.
95 ENTR	No update of either state vector	Prevents state vector updating (LM or CSM).

P20 has three alternative modes for controlling the rendezvous radar during target acquisition: the RR LGC Mode (R21), the RR Manual Mode (R23), and the RR Search Mode (R24). The LGC Mode or the Manual Mode can be selected by the astronaut at the beginning of P20; but the Search Mode can only be selected after the LGC Mode has failed to acquire the CSM.

The following flags are used during the operation of P20:

First Pass Flag — set denotes first pass through P20, P22.
Surface Flag — set denotes the LM is on the lunar surface (P22 only).
Update Flag — set denotes updating by marks allowed.
Track Flag — set permits vehicle attitude to be controlled to align LM Z-axis to CSM LOS during navigation (P20) and targeting (P30s).
Rendezvous Flag — set denotes P20 or P22 is running; reset when P20/P22 terminates.
Search Flag — set denotes RR Search Mode is being used.
Manual Acquire Flag — set denotes manual acquisition of CSM has been achieved.
R04 Flag — set denotes R04 is running.
No RR Monitor Flag — set denotes the disabling of the angle monitor function of R25; occurs during RR Manual Mode.
LOSCM FLAG — set denotes LOS is being computed.
Designate Flag — set denotes RR Designate is requested or is in progress.
Continuous Designate Flag — set denotes continuous designate; LGC commands RR regardless of lock-on.
No Update Flag — set denotes stopping the update of the state vector with RR data. This is done by the astronaut whenever desired.
Reposition Flag — set denotes RR is being repositioned to the reference direction for present RR antenna mode.
Range Scale Flag — set denotes a change scale during RR/LR read.
Lock-on Flag — set denotes radar lock-on desired.

The Update flag controls state vector updating by P20. The flag is reset by VERB 37 and set by P20, P30, P32–35, P72–75; then it is reset during computations of the targeting programs, the P30s and P70s, so that P20 does not update the state vector during targeting program computations. It still reads the radar, however, and controls LM attitude.

The Track flag allows P20 (also P30s and P70s) to control vehicle attitude via R61 or R65, aligning the Z-axis to CSM LOS; it is reset by VERB 37 and set by the P20s, P30s, and P70s to assure tracking during navigation and targeting. The Track

flag is reset during the P40s, since they control LM attitude during a burn. When the Track flag is reset, P20 does nothing but wait for it to be set.

Upon the crew's selection of P20 (VERB 37 ENTR 20 ENTR), the program checks the Surface flag to ensure it is not set, i.e., the LM is not on the lunar surface. The state-vector-update option is automatically set to the LM. This setting may be changed at any time later by one of the following entries:

a. VERB 80 ENTR to update the LM state vector
b. VERB 81 ENTR to update the CSM state vector
c. VERB 95 ENTR to indicate no state-vector update.

The program then performs the IMU Status Check Routine (R02) and illuminates the PROG alarm light if the IMU is off or the IMU orientation is unknown. Should the PROG light be illuminated, the crew must key in VERB 05 NOUN 09 ENTR to see the appropriate alarm code displayed. (Alarm code 00210 is displayed if the IMU is not on; alarm code 00220 is displayed if the IMU orientation is unknown.) A flashing VERB 37 indicates that, as a result of the alarm, the program has entered the Final Automatic Request Terminate Routine (R00).

P20 then sets the Update Track, First Pass, and Rendezvous flags; resets the Search, Manual Acquire, and R04 flags; resets the No RR Monitor, LOSCM, Designate, and Continuous Designate flags.

The estimated range between the LM and the CSM is then determined by taking the vector difference between the LM and CSM position vectors, which are extrapolated to the present time using conic equations. If the range is greater than 400 n. mi., program alarm 00526 is stored, since the RR is unable to provide correct range information to the LGC, and the PROG light on the DSKY lights. The astronaut can key VERB 05 NOUN 09 to call the alarm. (He will also note the RNDZ RADAR NO TRACK light illuminate.) He can get a display of range and range rate by keying VERB 16 NOUN 54 ENTR; when the range is less than 400 n. mi., normal program processing continues. He can also key VERB 56 ENTR to perform the Terminate Tracking Routine (R56), terminate P20, and exit either to the other program in process or to R00.

After verifying that the range is less than 400 n. mi. (i.e., alarm code 00526 does not occur), P20 calls the Preferred Tracking Attitude Routine (R61) to align the LM +Z-axis along the LOS to the CSM. This ensures that the RR antenna will be designated in the correct antenna angular coverage region for operation. (Refer to

Figure 4.3.1-3.) This attitude permits the LM optical beacon (centered with respect to the LM +Z-axis with a beamwidth of approximately 60 deg) to be visible from the CSM for optical tracking.

The LM +Z-axis is directed along the LOS to the CSM by the Fine Preferred Tracking Attitude Routine (R65), which is called two times, to perform seven computations, during each nominal 64-sec RR data cycle, while tracking in R22.

RR data are not used to update the navigation equations if the RR is more than 30 deg from the LM +Z-axis, ensuring that the LM optical beacon will be received by the CSM, and that a reliable estimate of the RR angle biases will be made when processing the data.

The LGC then checks to ensure that the RR Auto Mode discrete is being received from the RR. This discrete signifies that the RR is on and has been placed under LGC control by the astronaut's setting the mode control switch of the RR in the LGC position. Reception of this discrete at this time indicates that the astronaut wants to use the RR LGC Mode of target acquisition.

If the RR Auto Mode discrete is not present, and P20 is the only program running, a request is made to the astronaut via flashing VERB 50 NOUN 25 to select the RR Manual Mode by keying in ENTR (as described in paragraph 4.3.1.3.1), or to reselect the RR LGC Mode by placing the RR mode control switch in the LGC position and keying in PRO. If P20 is not the only program running, program alarm 00514 (indicating that the RR has been switched out of the Auto Mode) will be issued to avoid a conflict in the DSKY displays between P20 and other programs. Should this alarm occur, the astronaut can either terminate P20 via R56 (keying in VERB 34 ENTR or VERB 56 ENTR), or reselect the RR Auto Mode by again placing the RR mode control switch in the LGC position and keying in PRO.

If the LGC determines that the RR LGC Mode was selected (i.e., RR Auto Mode discrete is being received), the program next checks to ensure that the RR CDUs are not being zeroed. They are zeroed initially by the RR Monitor Routine (R25) when the RR Auto Mode discrete is first received from the RR, and are not zeroed again by R25 unless the status of the RR Auto Mode discrete changes. A check is then made to determine if either the Manual Acquire or Search flag is set, signifying that the RR Manual Mode or the RR Search Mode is being used. Since the present mode is assumed to be the RR LGC Mode, these flags should not be set.

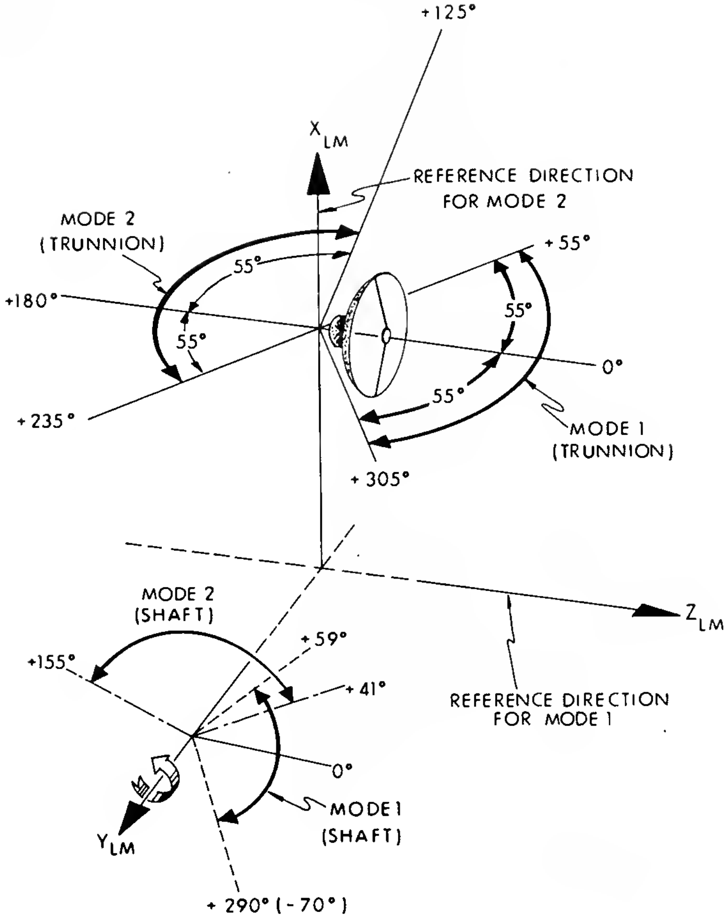


Figure 4.3.1-3. RR Antenna Shaft and Trunnion LOS Tracking Regions

Just before entering the RR Designate Routine (R21), the program makes a precision update of the CSM and LM permanent state vectors, and checks the Rendezvous and Track flags. P20 then calls the RR Designate Routine (R21). The RR Track Enable discrete is automatically removed from the RR to ensure RR response to R21 commands. R21 initially points the RR antenna along the reference direction of Mode 1. (See Figure 4.3.1-3.) If R21 fails to acquire the CSM, the RR Search Mode is initiated, as described in paragraph 4.3.1.3.2. The LOS range vector ($\underline{r}_{LOS}$) and the velocity ($\underline{v}_{LC}$) of the CSM with respect to the LM are computed using the CSM and LM position and velocity vectors ($\underline{r}_C$, $\underline{v}_C$, $\underline{r}_L$, $\underline{v}_L$). After the computation of $\underline{r}_{LOS}$ and $\underline{v}_{LC}$, a check is made to determine if the LOS is within the angular tracking limits of either RR antenna mode, as shown in Figure 4.3.1-3. (Note that the limits shown in the figure are not the antenna gimbal mechanical limits, but the LOS limits within which the RR should track satisfactorily.) If the LOS is within the angular tracking limits of one of the RR antenna modes, R21 will ensure that the RR antenna is in that mode before designating the RR antenna along the LOS.

R21 designates the RR toward the CSM by issuing rate commands to the RR antenna gyros approximately every 0.5 sec. An approximate update for the LOS motion is made to $\underline{r}_{LOS}$ about every 0.5 sec until the counter N in R21 is decremented from 3 to 0. When N equals 0, the routine computes new values of $\underline{r}_{LOS}$ and $\underline{v}_{LC}$, sets N equal to 3, and begins another designate command cycle until RR lock occurs or until 60 commands have been issued.

During R21, a check is made to see if the RR is within 0.5 deg of the present LOS range vector ($\underline{r}_{LOS}$). If so, the RR track enable discrete is issued to the RR enabling the angle-tracking servos to track the target if its range-rate tracking network has already acquired the target. Issuance of this discrete also initiates the RR range tracker search if the velocity tracker has already acquired the CSM.

Approximately every 0.5 sec, R21 also checks to determine if the RR data good discrete is present. This discrete is sent to the LGC by the RR when lock-on is achieved in range and range rate, and the RR track enable discrete has been received from the LGC. If the RR data good discrete has not been received after issuing rate commands to the RR gyros 60 times (K = 0), the RR track enable discrete is removed and program alarm 00503 is issued, indicating a radar antenna designate fail. The astronaut then either repeats the designate process, or goes to the RR Search Mode by keying in PRO (VERB 33 ENTR) to begin the RR Automatic Search Routine (R24).

If the RR data good discrete is received during the designate process, R21 is terminated, and the shaft and trunnion angles indicating the direction of the RR antenna are displayed to the astronaut via VERB 50 NOUN 72 so he can confirm lock-on by the main radiation lobe before entering the RR Data Read Routine (R22). This confirmation is made either through the crew optical alignment sight (COAS), or the RR signal-strength meter. If the astronaut exercises manual control of the RR to ensure it is tracking on the main lobe, he does not key in PRO until after he has placed the RR mode control switch in the LGC position, and the RADAR panel NO TRACK light is extinguished. After confirmation of main lobe lock-on, the Rendezvous and Track flags are checked to ensure that they are set before entering R22. R22 cycles through R65, the Fine Preferred Tracking Attitude Routine (Figure 4.3.1-16), before branching off for the first RR data sample.

The RR Data Read Routine (R22) obtains an RR mark—complete set of four data components (range, range rate, shaft angle, and trunnion angle)—from the RR at approximately one-minute intervals throughout the rendezvous phase, except during powered maneuvers. In addition to these data, the time of the measurement and the three IMU gimbal angles are also recorded. The RR mark data is also automatically placed on the downlink for transfer to the AGS. This is done by setting a code word, which is on the rendezvous/prethrust downlist, to a special configuration indicating to the AGS that the RR mark data are good. A minimum of 50 sec must elapse between successive settings of the code word. During R22, R65 is repeatedly called to obtain continuous or fine LM +Z-axis tracking of the CSM. The interval between successive state vector update marks (that is, the interval required to obtain each four-component mark) is about 64 sec.

After each set of RR data is read, but before it is incorporated, the calculated LOS for the time of the reading is compared with that indicated by the RR CDUs. If the difference is more than 3 deg, the probability of sidelobe acquisition is large and PROG alarm code 00525 is issued. The astronaut will PRO to obtain a flashing VERB 06 NOUN 05, which displays $\Delta\theta$, the size of the angle between the computed and actual RR LOS, for sidelobe verification. If the size of the displayed $\Delta\theta$ indicates RR sidelobe lock, the astronaut should recycle to the RR Designate Routine (R21) by keying in VERB 32 ENTR. Otherwise he can request the LGC to incorporate the data by keying in PRO.

Prior to incorporation, a check is made on the magnitudes of the changes in position and velocity (δr, δv) that each of the four components of each mark (R, R-dot, β, and θ) cause in the state vector. If the δr or δv that results exceeds certain predetermined values, the magnitudes of the corrections will be displayed via VERB

06 NOUN 49. In addition, a source code will be displayed indicating which component of the mark (range = 1, range rate = 2, shaft angle = 3, trunnion angle = 4) caused the update that exceeded the δr, δv threshold; this can be useful in indicating the type of corrective action required.* The result of processing RR measurement data is an 8-dimensional estimate of the position, velocity, and RR angle bias. The improved estimate of the updated vehicle's relative state vector is used to compute rendezvous targeting parameters in other programs.

The W-matrix is automatically initialized from pad-loaded values when P20 is called for the first time. W-matrix gain diminishes as marks are taken and correlations within the matrix acquire errors with continued extrapolation, when the W-matrix is small, and also because of truncation. The W-matrix is, therefore, normally reinitialized at CDH to stored RMS position, velocity, and angle bias values. Because reinitializing to diagonal values destroys the cross-correlation terms in the corners of the matrix, two ways of reinitializing are allowed.

The astronaut can reinitialize before taking CDH marks, by keying in VERB 67 ENTR, and writing over the values displayed by VERB 06 NOUN 99. In this case the correlation terms are destroyed and several marks will be required to re-establish them.

If, before reinitialization, the astronaut wishes to change the values used to initialize the W-matrix, he can change the values by octal load, keying in VERB 21 ENTR, and using reinitialization values prescribed in the crew charts or in the flight plan. Alternatively, the astronaut can set up the reinitialization beforehand.

He can then permit three or four marks to be incorporated before keying VERB 93 ENTR, which will reinitialize the W-matrix to the prestored values when the next mark arrives. The VERB 67 approach is time consuming and difficult to perform between marks. Also it affects the W-matrix directly. The VERB 21, VERB 93 techniques allow the astronaut to load new values when it is convenient, far in advance of when he wants to reinitialize. The values put into the registers with VERB 21 do not affect the present W-matrix being used, nor does rediagonalization occur until a mark is processed following the reinitialization request via VERB 93 ENTR. This allows the correlation to reduce state-vector error buildup across the no-track period surrounding the burn. Subsequent marks then restore the correlation in the diagonal matrix.

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*Refer to Users' Guide paragraph 4.2.1 on CSM P20 for N49 mark incorporation.

4.3.1.3 Alternate Procedures

4.3.1.3.1 RR Manual Mode.—If P20 is the only program running, and the LGC indicates the auto mode discrete is not present (flashing VERB 50 NOUN 25, with checklist code 00201 in R1), the Manual Mode of target acquisition (R23) will be initiated if the astronaut keys ENTR in response to the display. This routine can only be performed, however, if P20 is the only program running (i.e., P20 is shown on the DSKY panel). Absence of this discrete at the beginning of P20 is ensured by not placing the RR mode control switch in the LGC position, as discussed in paragraph 4.3.1.1.

When the astronaut keys in ENTR to the flashing VERB 50 NOUN 25 display in P20, R23 is entered and the NO ANGLE MONITOR flag is set, the minimum deadband of the RCS DAP is selected, and the RR track enable discrete is issued to the RR. Issuing this discrete at this time ensures that no loss of RR angle tracking occurs when the mode control switch of the RR is placed in the LGC position after acquisition.

R23 next flashes VERB 50 NOUN 25 with code 00205 displayed in R1, requesting the astronaut to change the RR control switch to the SLEW position and perform manual acquisition of the CSM. If manual acquisition is achieved, the astronaut places the RR mode control switch in the LGC position, waits until the radar panel NO TRACK light is extinguished, and keys in PRO. When the RR mode control switch is placed in the LGC position, RR range tracking is interrupted and a new range search is initiated. When the RR acquires the target in both range and range rate, the NO TRACK light is extinguished, thus ensuring RR-tracking-network lock-on before entering R22.

After PRO is keyed in response to flashing VERB 50 NOUN 25, the LGC determines if the RR is within the limits of the present coverage mode. If it is not, program alarm 00501 is issued, and the astronaut either terminates the routine by keying in VERB 56 ENTR or VERB 34 ENTR (R56), or repeats the acquisition process via R61 by keying in recycle (VERB 32 ENTR). The astronaut uses R61 to realign the LM +Z-axis with the target LOS whenever he elects to repeat the manual acquisition process.

Once the acquired RR is returned to LGC control and the RR is within the present antenna mode limits, the astronaut-specified deadband is restored, and the No Angle Monitor flag is reset in R23. R23 then exits to P20 which sets the Manual Acquire flag and calls R22.

4.3.1.3.2 RR Search Mode.—If R21 fails to acquire the CSM (alarm code 00503), the RR Search Mode can be selected by the astronaut by keying in PRO. R24 designates the RR antenna in a hexagonal search pattern about the estimated LOS, as illustrated in Figure 4.3.1-4. This search pattern requires approximately 42 sec to complete.

The LGC sets the Search flag, and the RR track enable discrete is issued to the RR. This discrete is reissued at each corner of the search pattern in case it has been removed by some source, such as R25 (the RR Monitor Routine). Approximately every 6 sec, the position and velocity vectors of the CSM and LM are used to compute the desired RR pointing direction ($\underline{u}_D$), which is along $\underline{u}_{LOS}$ for the first 6 sec and steps counterclockwise to the six corners of the search pattern at 6-sec intervals. A check is made on $\underline{u}_D$ with respect to the angular coverage modes of the RR antenna. If $\underline{u}_D$ is not within the limits of either mode, the PROG alarm light is turned on, alarm code 00527 is stored, and the search pattern is stopped.

If the astronaut wishes to continue the search, he must reestablish the preferred tracking attitude via the Preferred Tracking Attitude Routine (R61). When $\underline{u}_D$ is within the limits and the correct antenna mode has been established, R24 designates the RR by issuing rate commands to the RR gyros about every 0.5 sec, with approximate corrections each time for lag error and target motion.

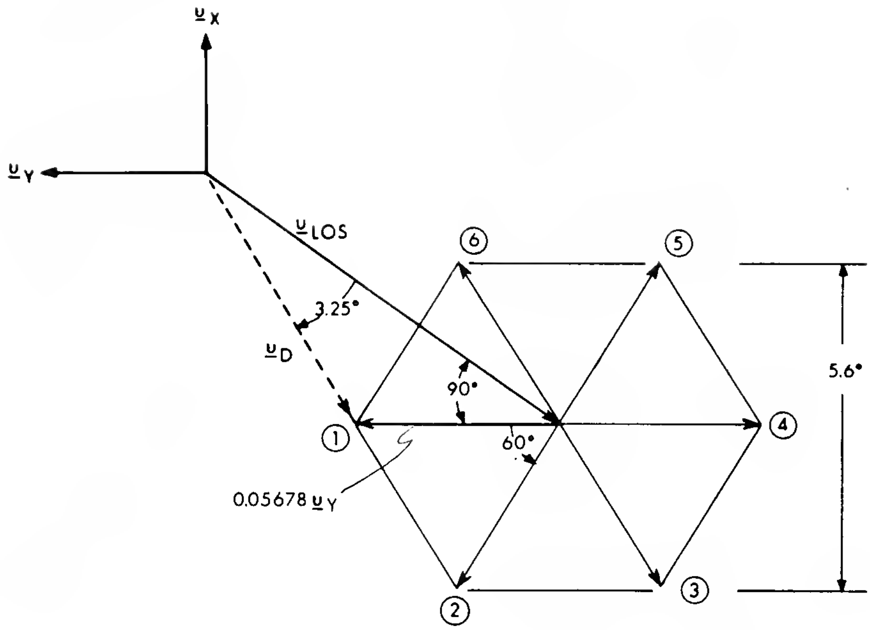
A periodic check is made to see if the RR data good discrete is being received from the RR, signifying the RR has acquired the target in range and range rate. This information is displayed via flashing VERB 16 NOUN 80. If the discrete is present, R1 is changed from 00000 to 11111, and the search is stopped.

The astronaut then checks to see if acquisition was obtained with the main radiation lobe of the RR. By manually altering the RR antenna position and observing the RR SIGNAL STRENGTH meter, he should be able to distinguish the main lobe from any sidelobes.

Having achieved and verified main lobe lock-on, the astronaut places the RR mode control switch in the LGC position, waits until the NO TRACK light is extinguished, and keys PRO in response to the flashing VERB 16 NOUN 80.

4.3.1.4 Associated Routines

The routines discussed below are those associated with P20 during the nominal and alternate procedures discussed above. The routines are presented here in numerical order, rather than in the order they occur in P20.



Note: This is the search pattern as viewed from the CSM.

Figure 4.3.1-4. RR Search Pattern

4.3.1.4.1 <u>IMU Status Check Routine (LM R02).</u>—This routine is called by programs requiring an aligned IMU. (Refer to Figure 4.3.1-5.) R02 checks the IMU operate bit and the IMU orientation (REFSMMAT) flag. If the ISS is not on, program alarm 00210 will be stored and the PROG lamp will light. If the IMU orientation is not known by the LGC, program alarm 00220 will be stored and the PROG lamp will light. By keying VERB 05 NOUN 09 into the DSKY the astronaut can have the stored alarm codes displayed to him for verification of the associated condition.

4.3.1.4.2 <u>RR/LR Self-Test Routine (LM R04).</u>—This routine provides DSKY displays and LGC downlink information to support the self-tests of the rendezvous radar and the landing radar. (Refer to Figure 4.3.1-6.) It is selected manually by DSKY entry of VERB 63 ENTR in conjunction with manual selection of the appropriate radar self-test at the LM console. (The radar test switch-position settings are RNDZ, OFF, and LDG.) R04 may be selected only when all of the following conditions are met:

a. The Track Flag is not set.
b. R12 and R77 not running.
c. No other extended verb is in progress.
d. A priority display is not using the DSKY.

If all of the above conditions are not met, the OPR ERR light will be illuminated. If R04 is selected during P63 before AVERAGE-G on, it must be terminated before R12 begins running at TIG-30 seconds in order to prevent a conflict with R12 which can result in degradation of the LM state vector.

The RR heaters must be in the operating position at least one hour before the selection of R04. Whenever a range or range-rate measurement is obtained from the RR, the RR data good discrete is also checked. If it is missing, the TRACKER fail light is illuminated. Self-testing is terminated by keying in VERB 34 ENTR.

4.3.1.4.3 <u>LR/RR Read Routine (LM R20).</u>—This routine reads the LR/RR parameter requested by the calling routine and performs various checks to ensure the system is operating correctly. (Refer to Figure 4.3.1-7.) The routine issues a program alarm, code 00520, if no radar sampling has been requested from the radar at this time; occurrence of the alarm is indicated to the crew by illumination of the PROG lamp. If the routine is unable to obtain "good" RR samples on each required pass—meaning that either the data good discrete is not present, or the RR CDU has failed—the TRACKER fail light illuminates.

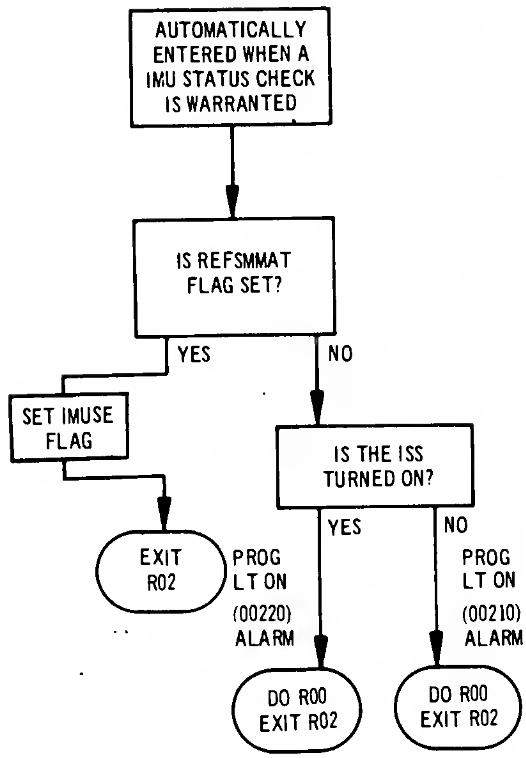


Figure 4.3.1-5. IMU Status Check Routine (LM R02)

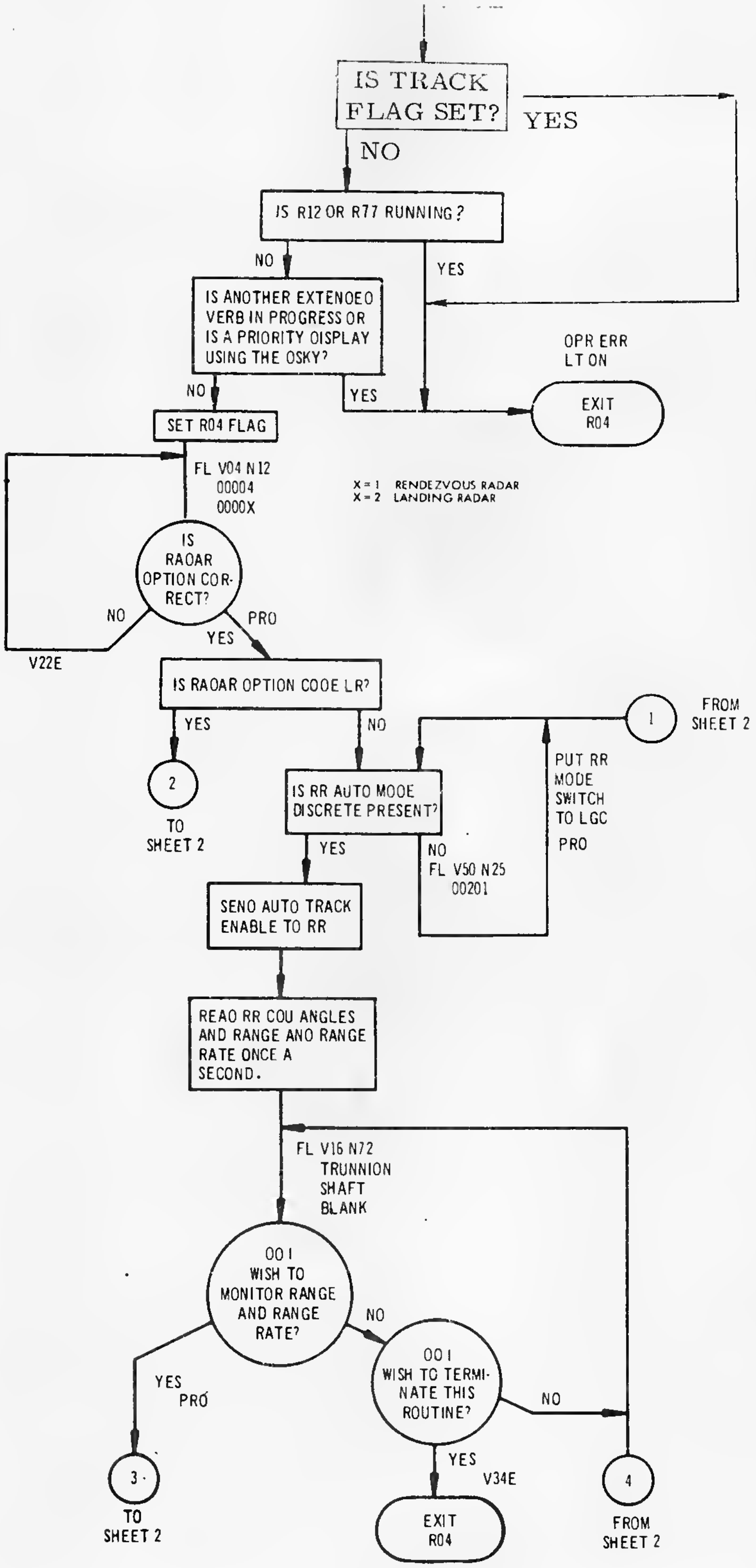


Figure 4.3.1-6. RR/LR Self-test Routine (LM R04)(Sheet 1 of 2)

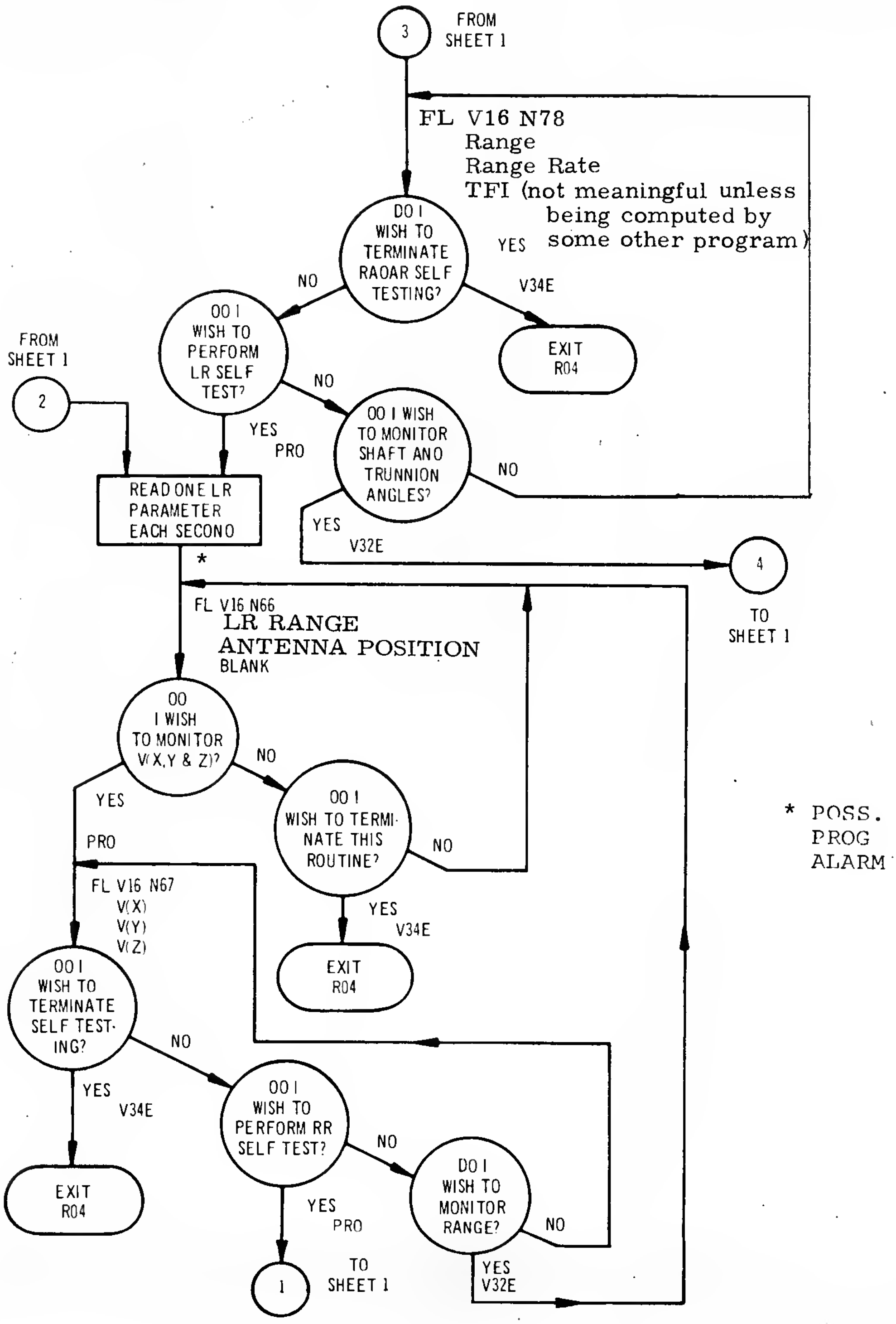


Figure 4.3.1-6. RR/LR Self-test Routine (LM R04) (Sheet 2 of 2)

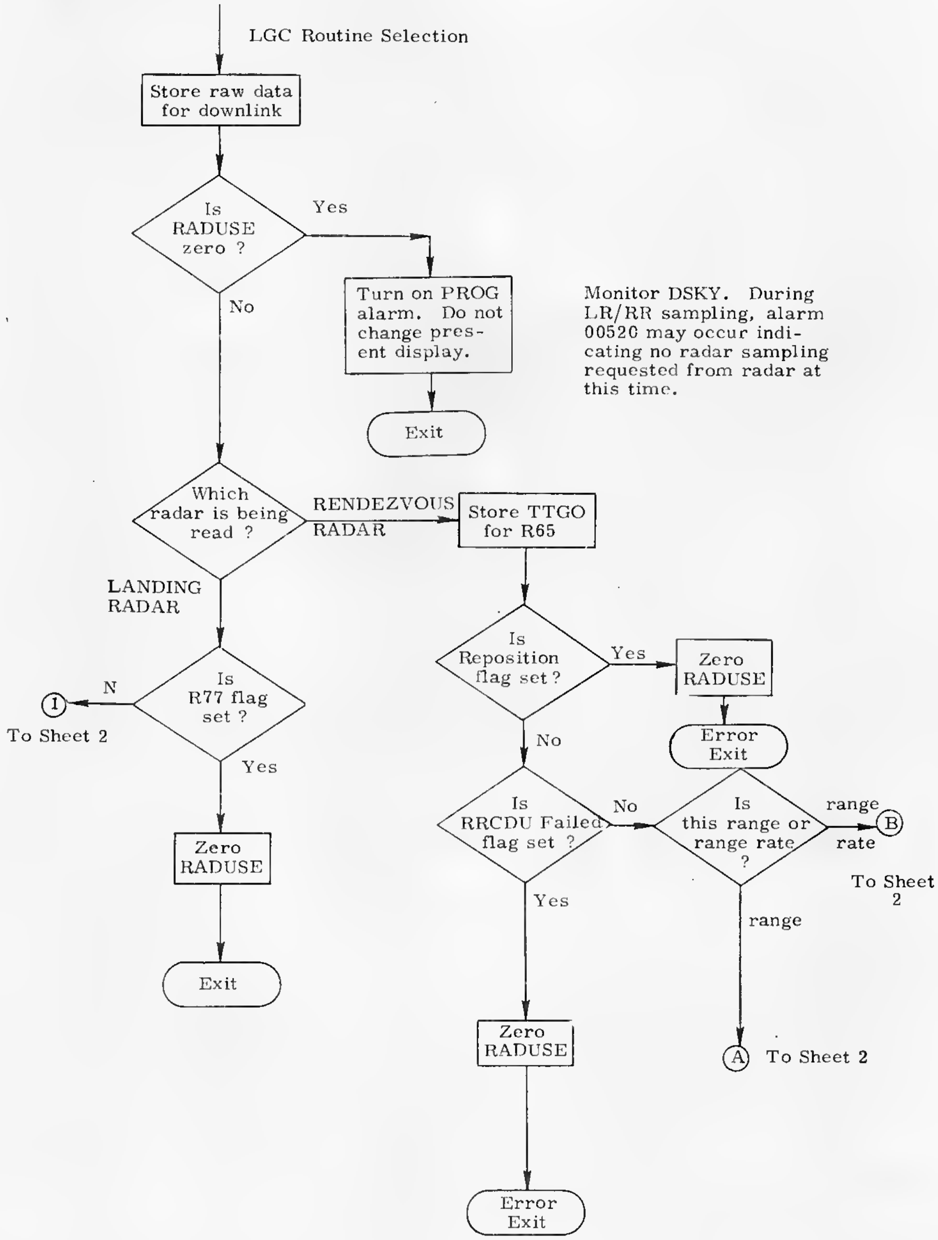


Figure 4.3.1-7. LR/RR Read Routine (LM R20) (Sheet 1 of 3)

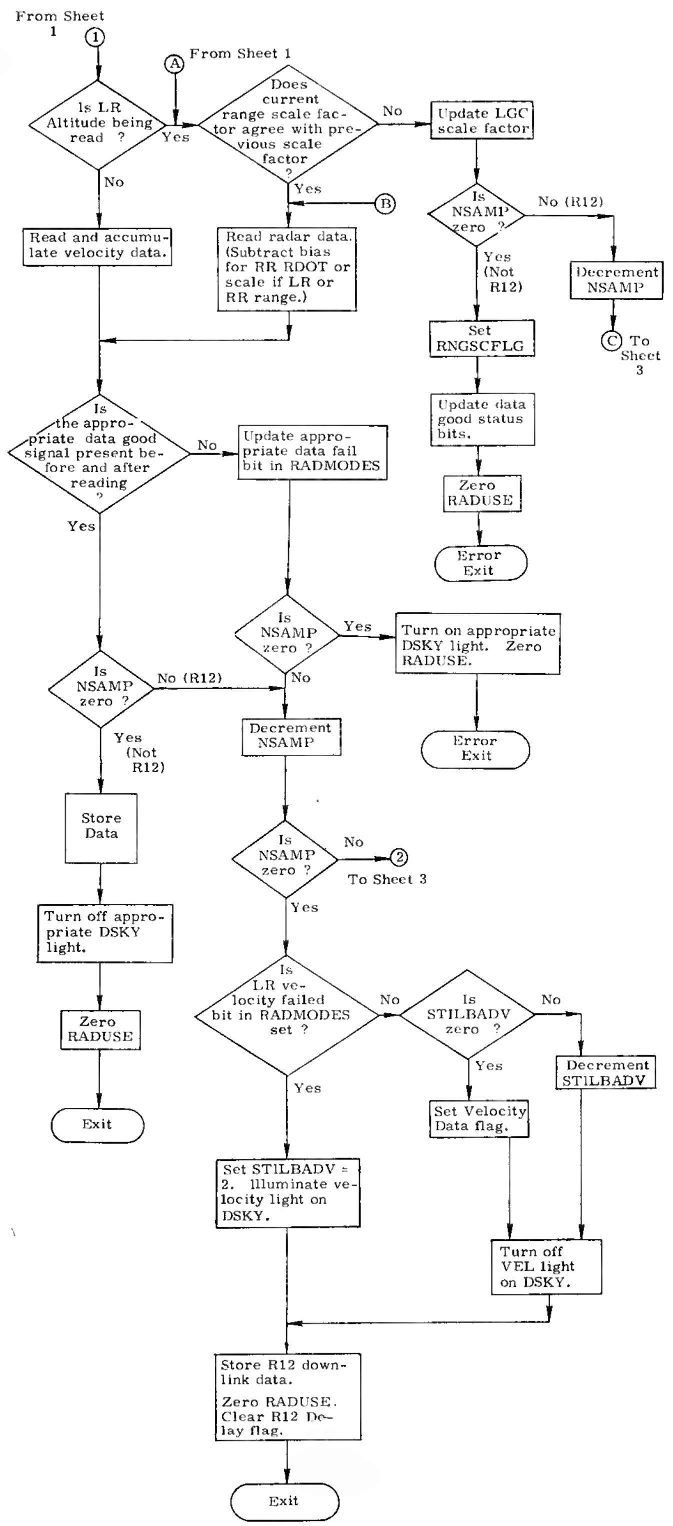


Figure 4.3.1-7. LR/RR Read Routine (LM R20) (Sheet 2 of 3)

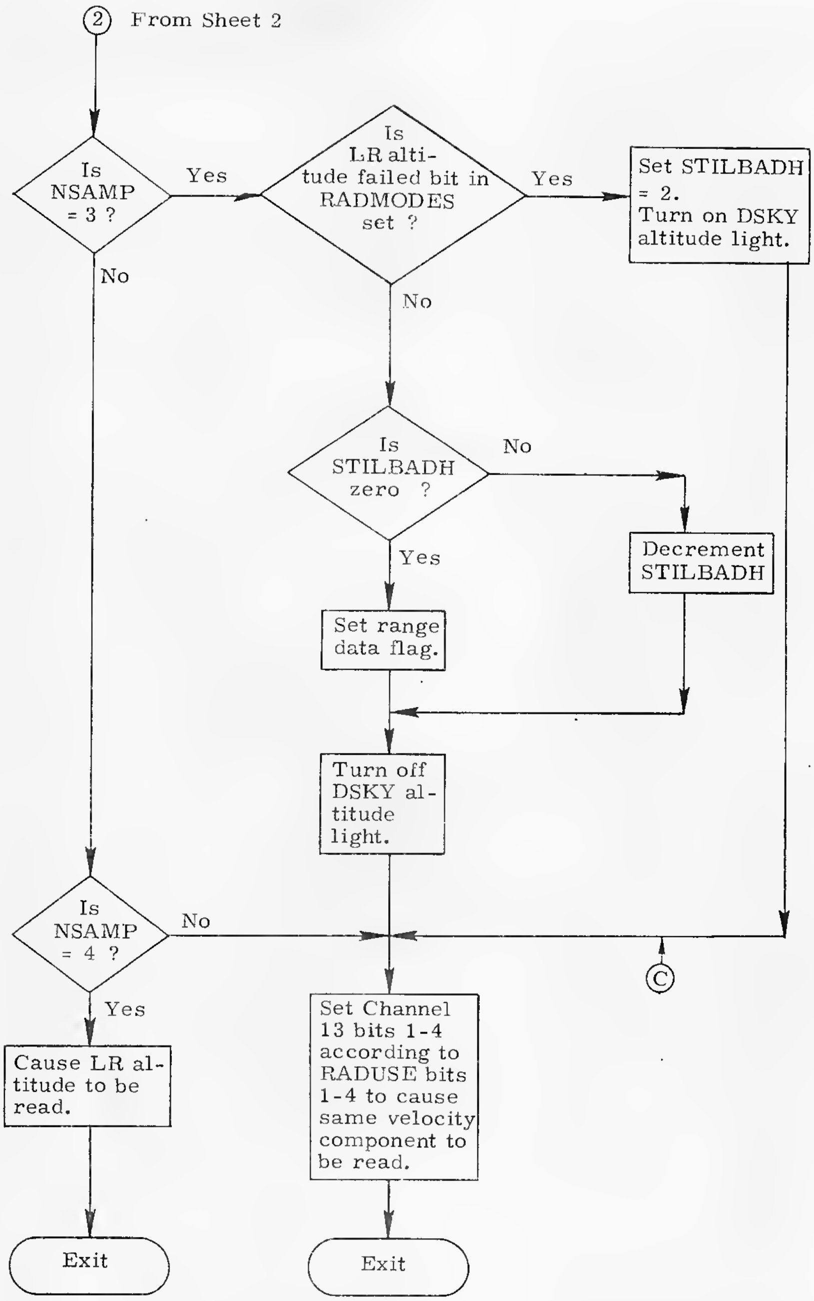


Figure 4.3.1-7. LR/RR Read Routine (LM R20) (Sheet 3 of 3)

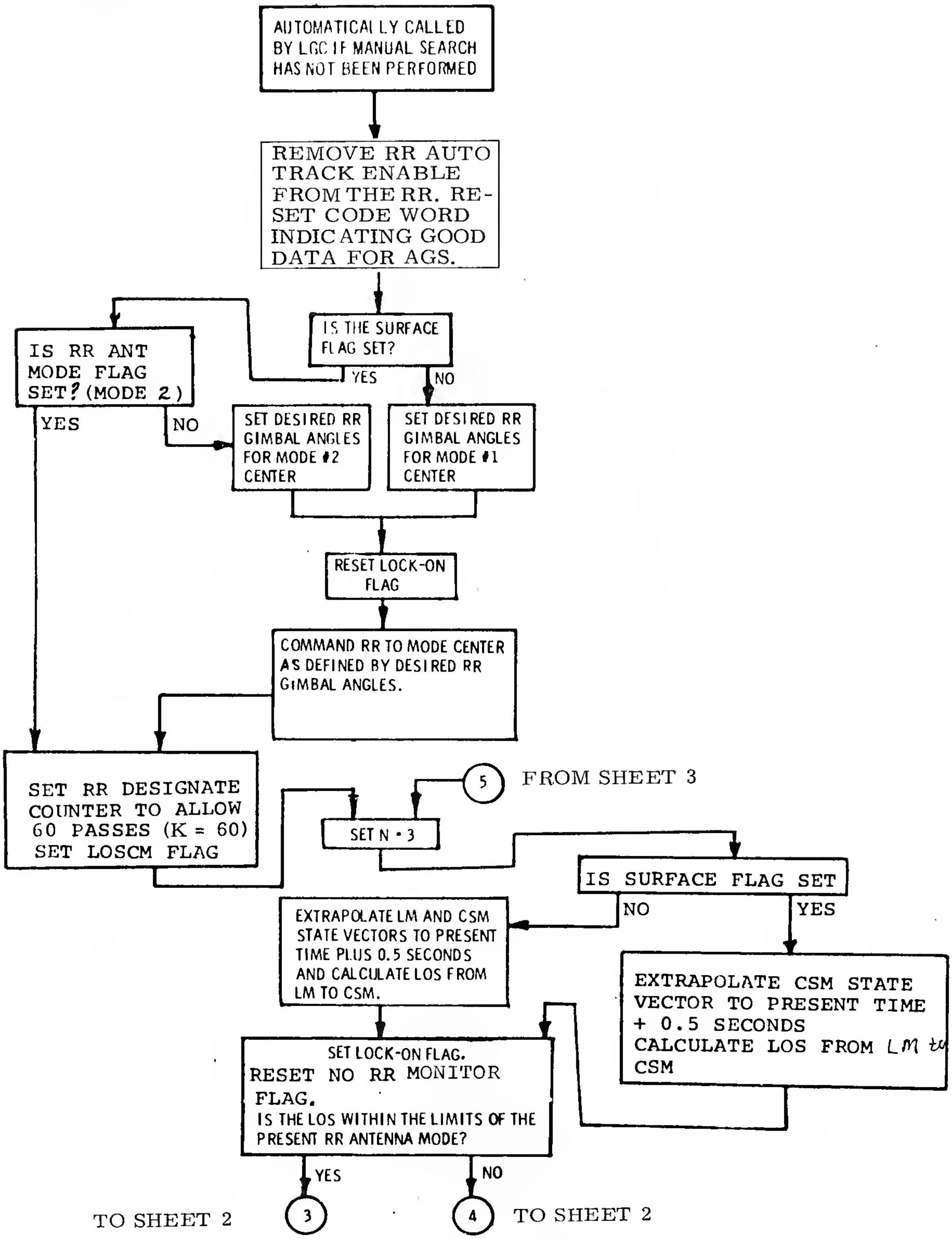


Figure 4.3.1-8. RR Designate Routine (LM R21) (Sheet 1 of 3)

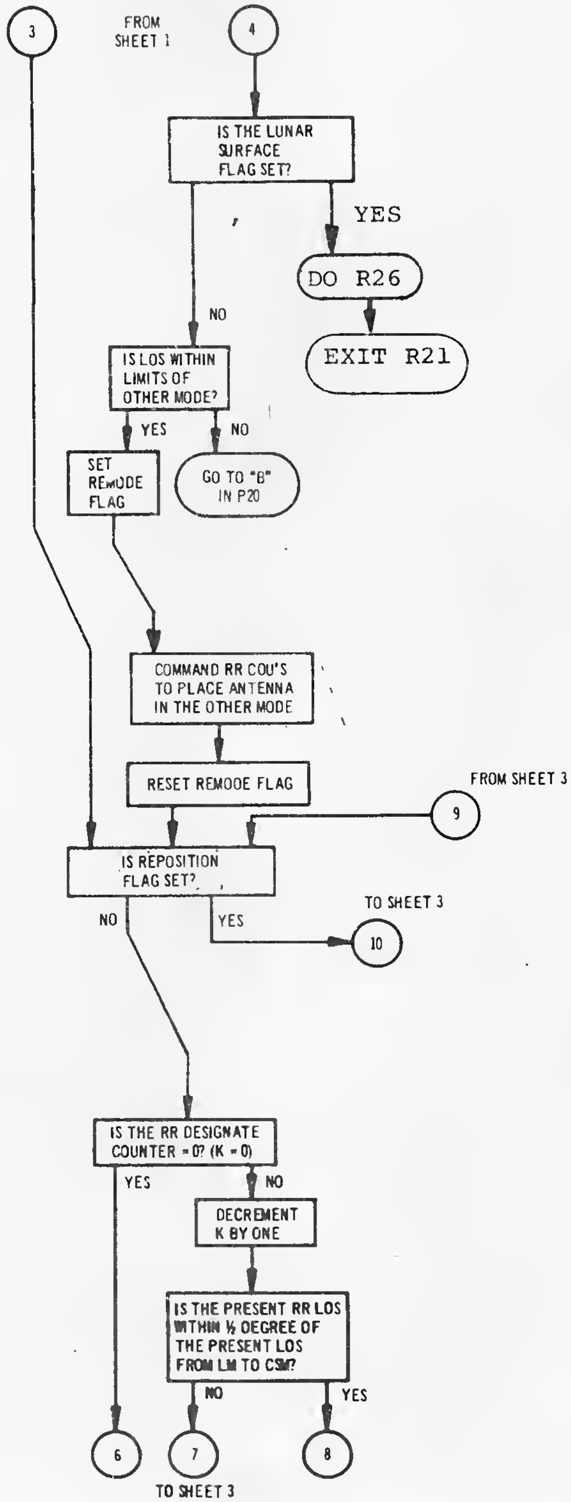


Figure 4.3.1-8. RR Designate Routine (LM R21) (Sheet 2 of 3)

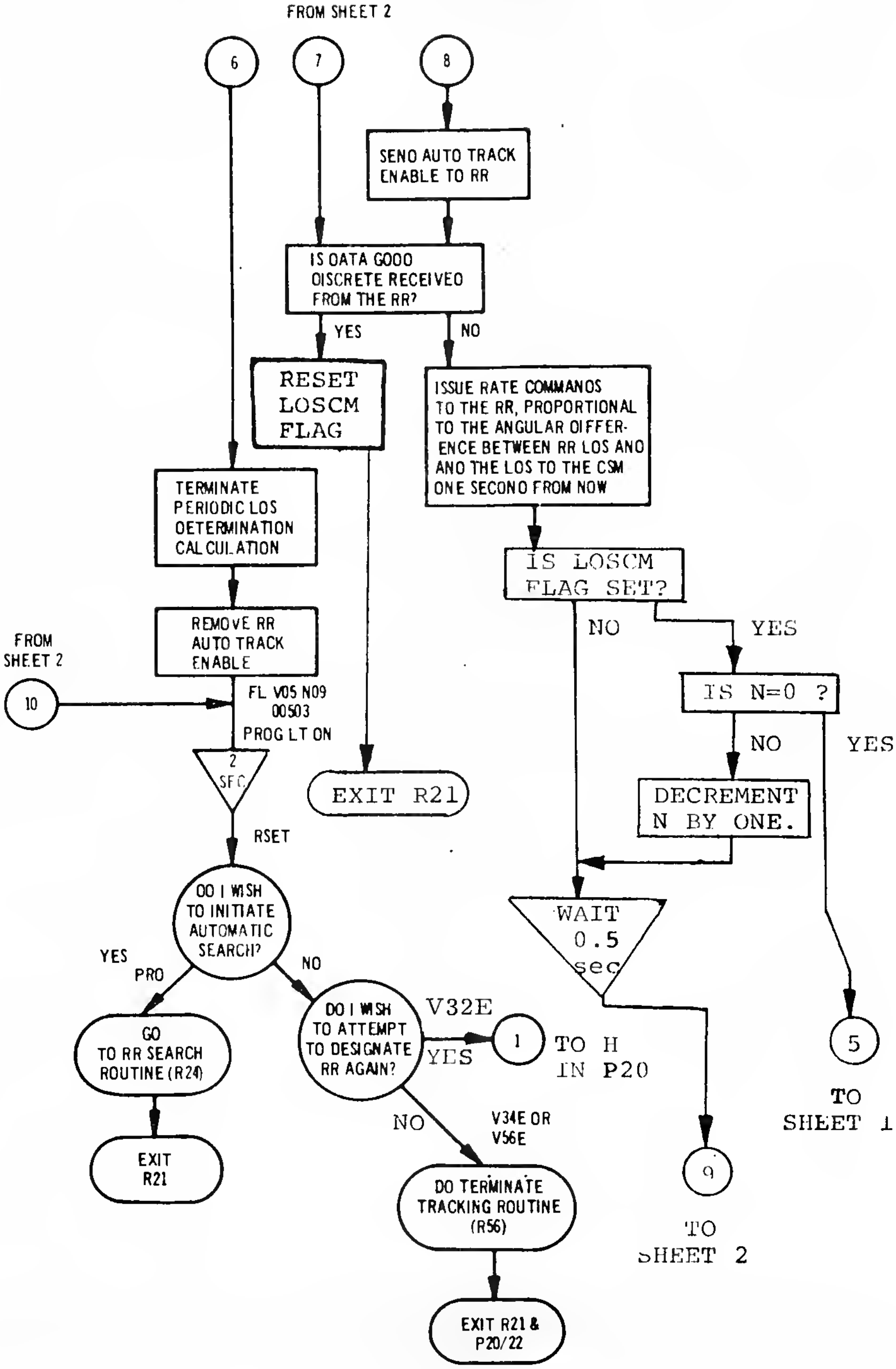


Figure 4.3.1-8. RR Designate Routine (LM R21) (Sheet 3 of 3)

4.3.1.4.4 RR Designate Routine (LM R21).—This routine is automatically called by P20. The routine points the RR at the CSM until automatic acquisition of the CSM is accomplished or until alarm code 00503 is stored, the PROG light is lit, and VERB 05 NOUN 09 flashes requesting response. (Refer to Figure 4.3.1-8.) The RR servos are commanded by the LGC, after the LGC issues the track enable discrete, until range-rate lock-on is achieved by the RR or until alarm code 00503 indicates R21 is unable to acquire the CSM.

4.3.1.4.5 RR Data Read Routine (LM R22).—This routine is automatically called by P20. (Refer to Figure 4.3.1-9.) R22 processes the automatic RR data in order to obtain the range, range rate, shaft angle, and trunnion angle between the LM and the CSM. These data are used to update the LM or the CSM state vector. R22 calls for R65 to maintain the LM +Z-axis aligned along the LOS from the LM to the CSM within the deadband of the DAP while P20 is in progress. Alarm code 00525 will occur (via flashing VERB 05 NOUN 09) if the delta theta (the difference between the RR indicated LOS and the state vector-indicated LOS) is greater than 3 deg. Due to the length of time involved in various computations of this routine, a call is made to R65 to ensure preferred tracking attitude is maintained.

4.3.1.4.6 RR Manual Acquisition Routine (LM R23).—This routine is used to acquire the CSM by manual operation of the rendezvous-radar antenna while the LM is in flight. (Refer to Figure 4.3.1-10.) The routine is automatically called by P20 in response to an astronaut request for a manual acquisition. R23 can be selected only when P20 is not running in conjunction with another program. Alarm code 00501 (flashing VERB 05 NOUN 09) indicates that the LOS to the CSM is outside the allowable limits of the present RR antenna mode.

4.3.1.4.7 RR Search Routine (LM R24).—This routine generates a search pattern to acquire the CSM when the RR has failed to acquire the CSM in the automatic mode. (Refer to Figure 4.3.1-11.) R24 allows the astronaut to confirm that reacquisition has not been by sidelobe. The routine is automatically called by R21 in response to an astronaut request for a search acquisition. If the desired RR LOS is not within the limits of either RR mode, a 00527 alarm is stored and the PROG lamp lit to indicate that a vehicle maneuver is required.

4.3.1.4.8 RR Monitor Routine (LM R25).—This routine is automatically called every 0.48 sec by an automatic program interrupt whenever the LGC is on. It monitors the RR status with respect to mode changes, RR CDU failure, and RR gimbal positions. (Refer to Figure 4.3.1-12.) If the RR gimbal angles exceed predefined limits (see Figure 4.3.1-3), R25 commands the RR gimbals to one of two reference

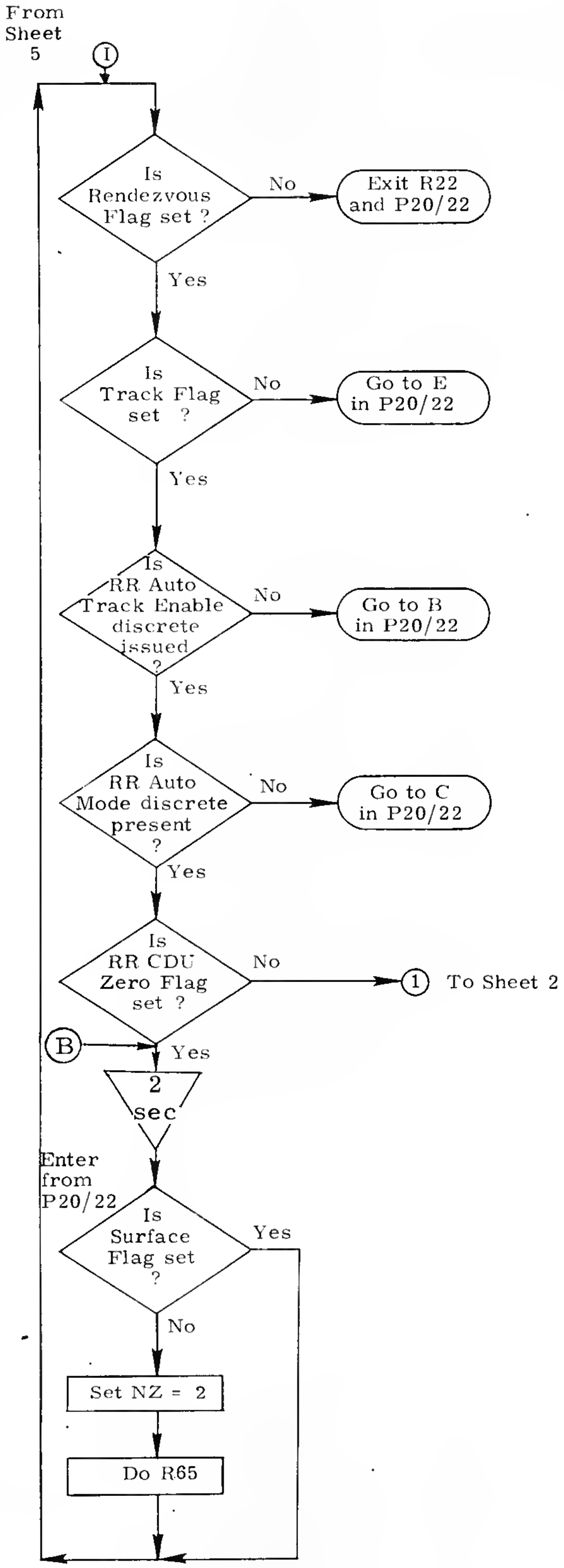


Figure 4.3.1-9. RR Data Read Routine (LM R22)
(Sheet 1 of 6)

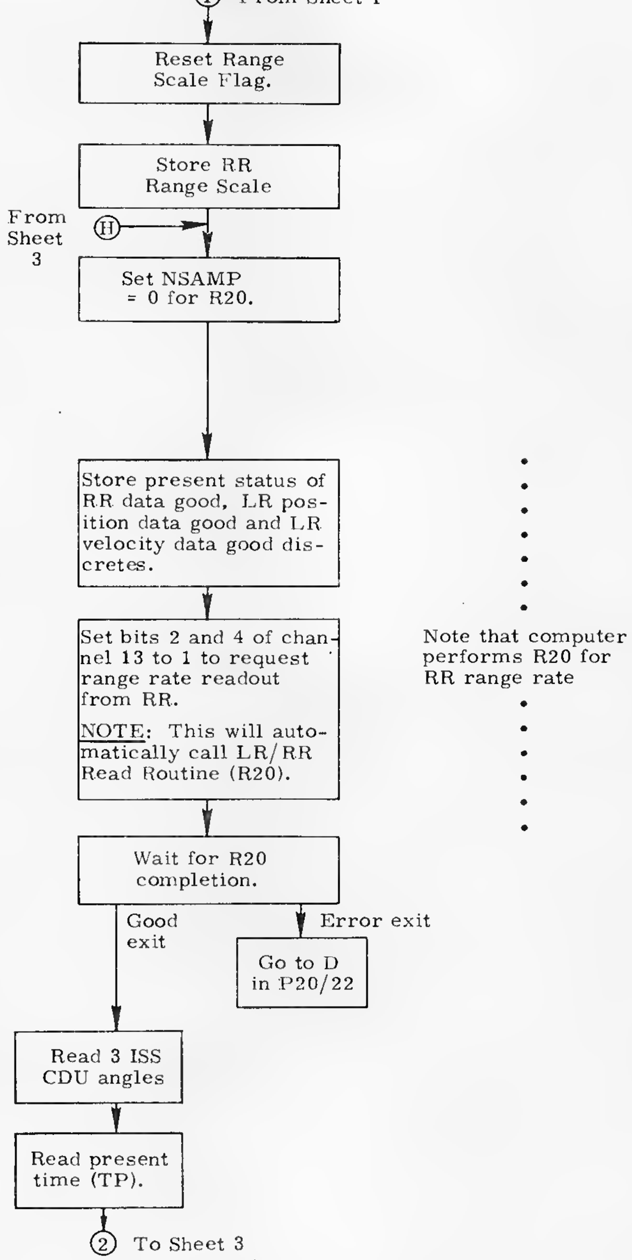


Figure 4.3.1-9. RR Data Read Routine (LM R22) (Sheet 2 of 6)

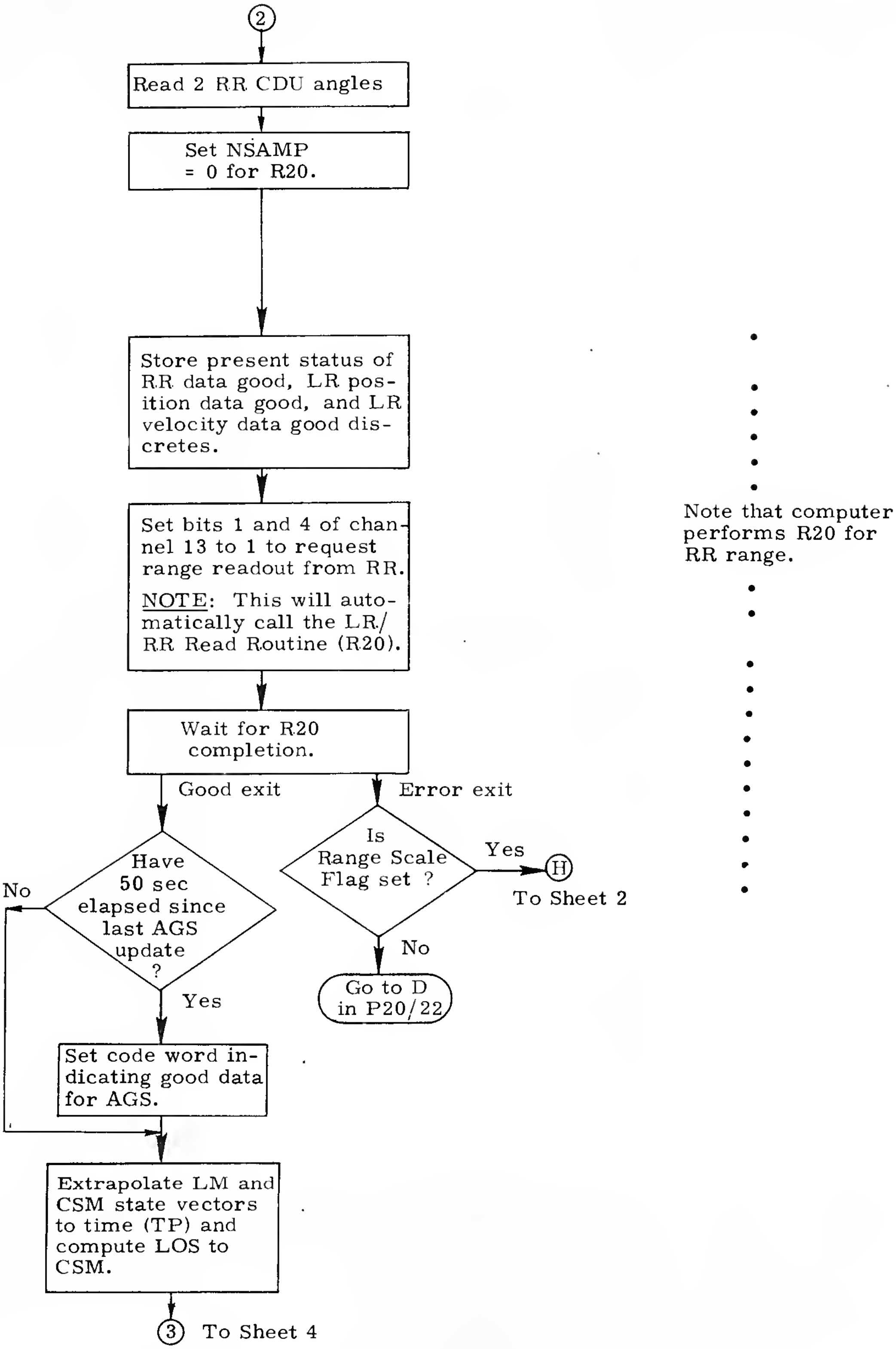


Figure 4.3.1-9. RR Data Read Routine (LM R22) (Sheet 3 of 6)

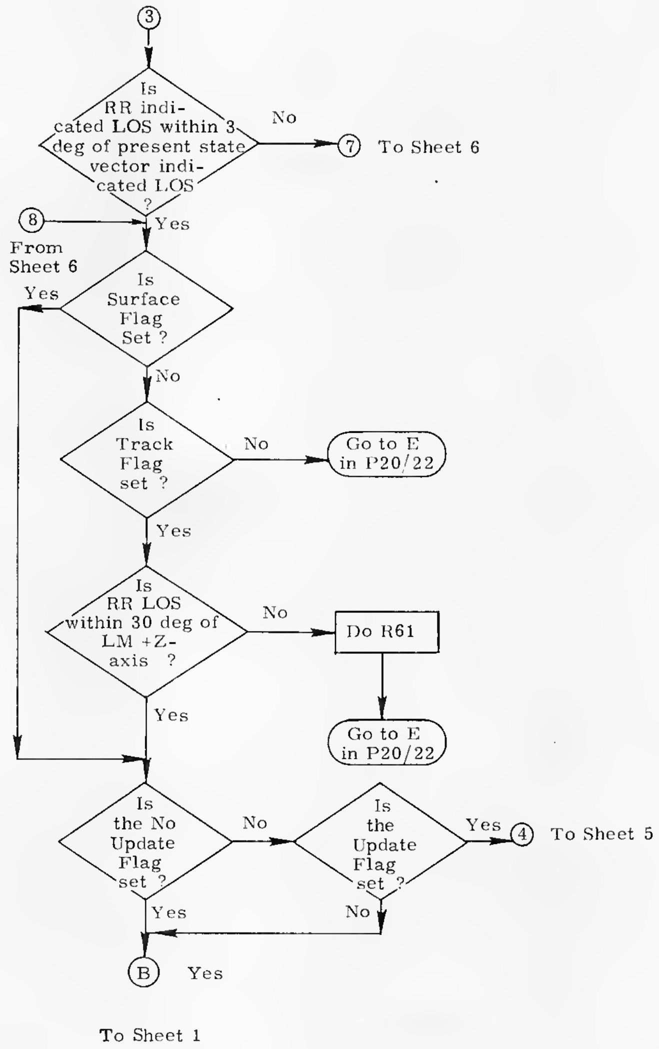


Figure 4.3.1-9. RR Data Read Routine (LM R22) (Sheet 4 of 6)

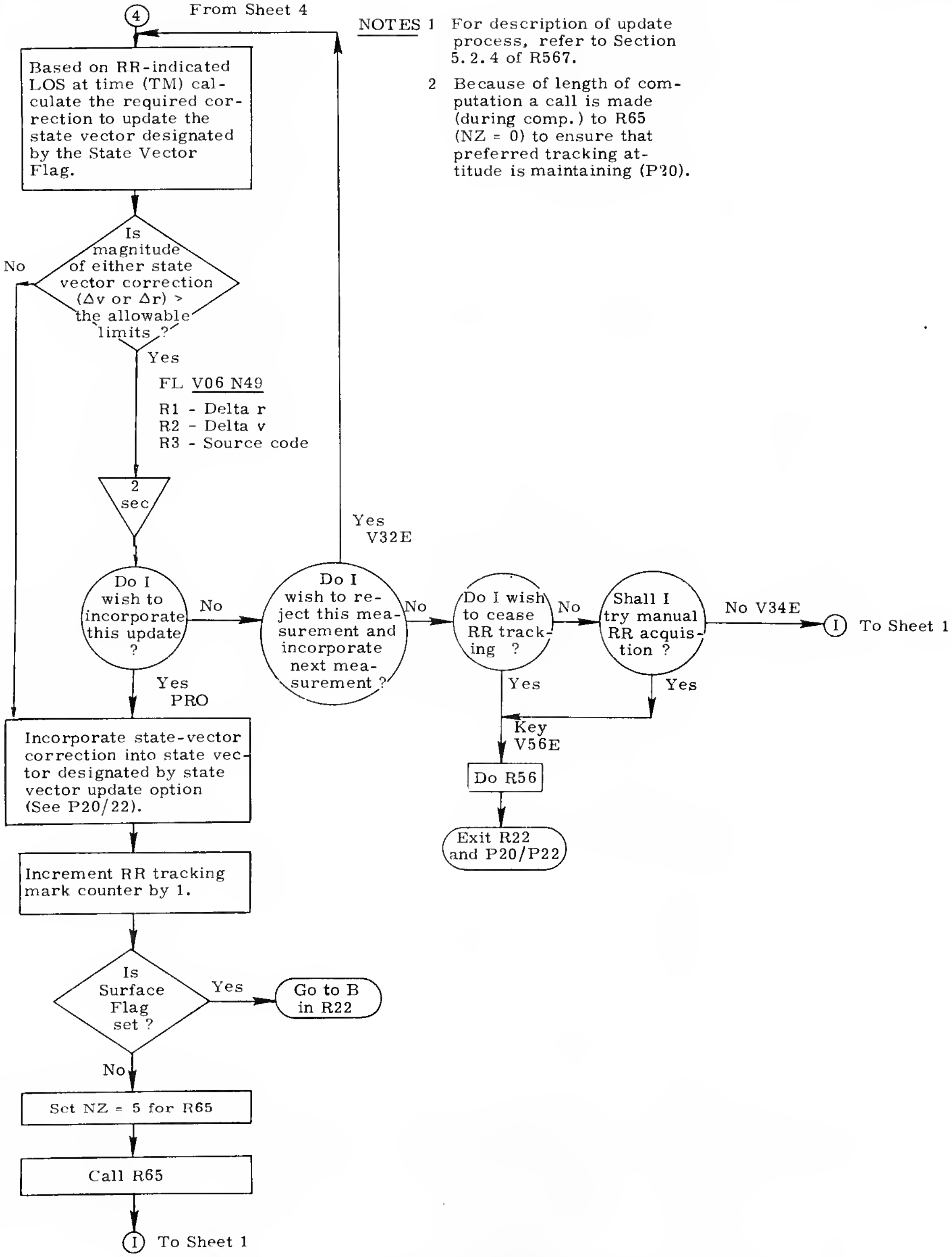


Figure 4.3.1-9. RR Data Read Routine (LM R22) (Sheet 5 of 6)

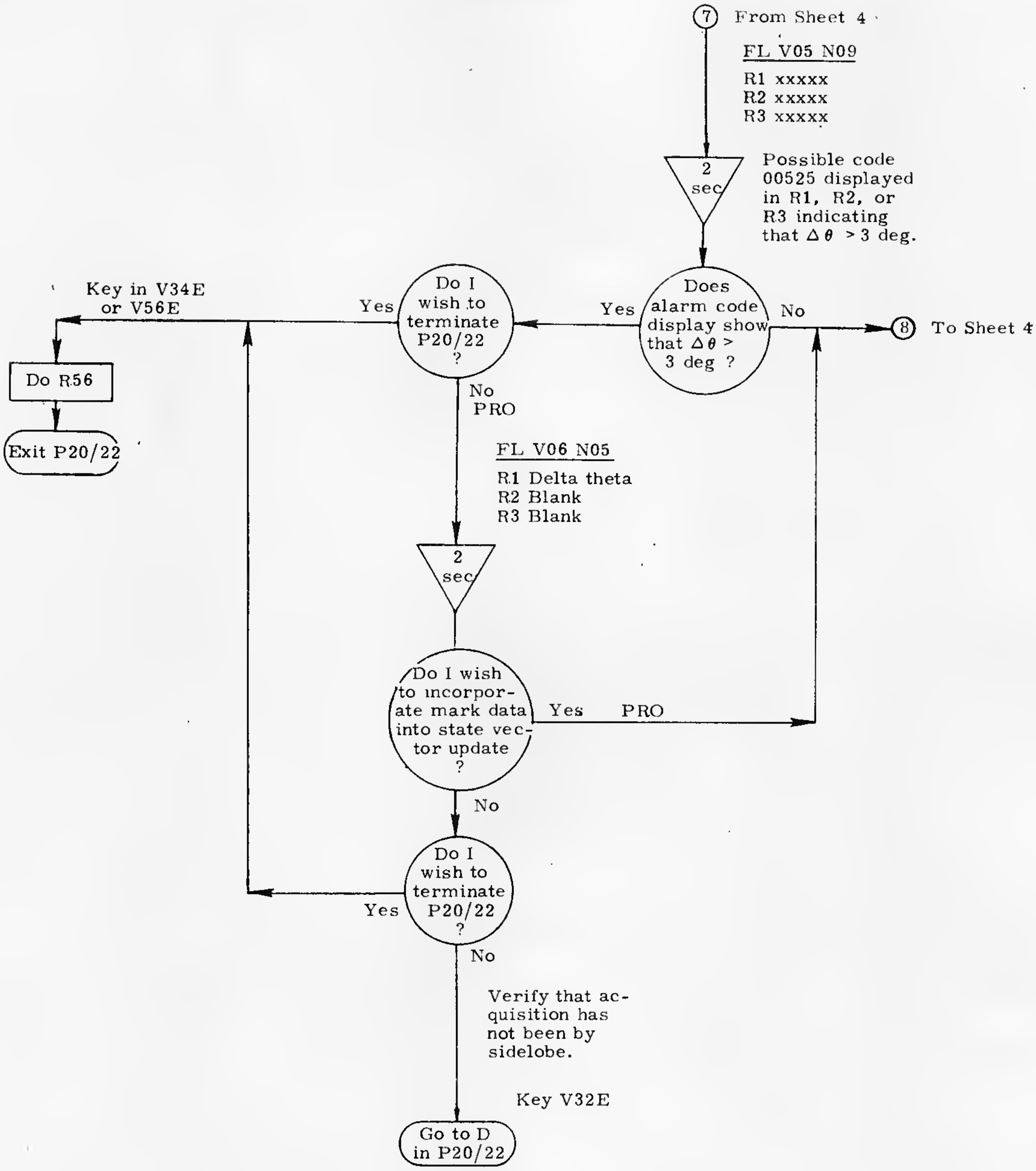


Figure 4.3.1-9. RR Data Read Routine (LM R22) (Sheet 6 of 6)

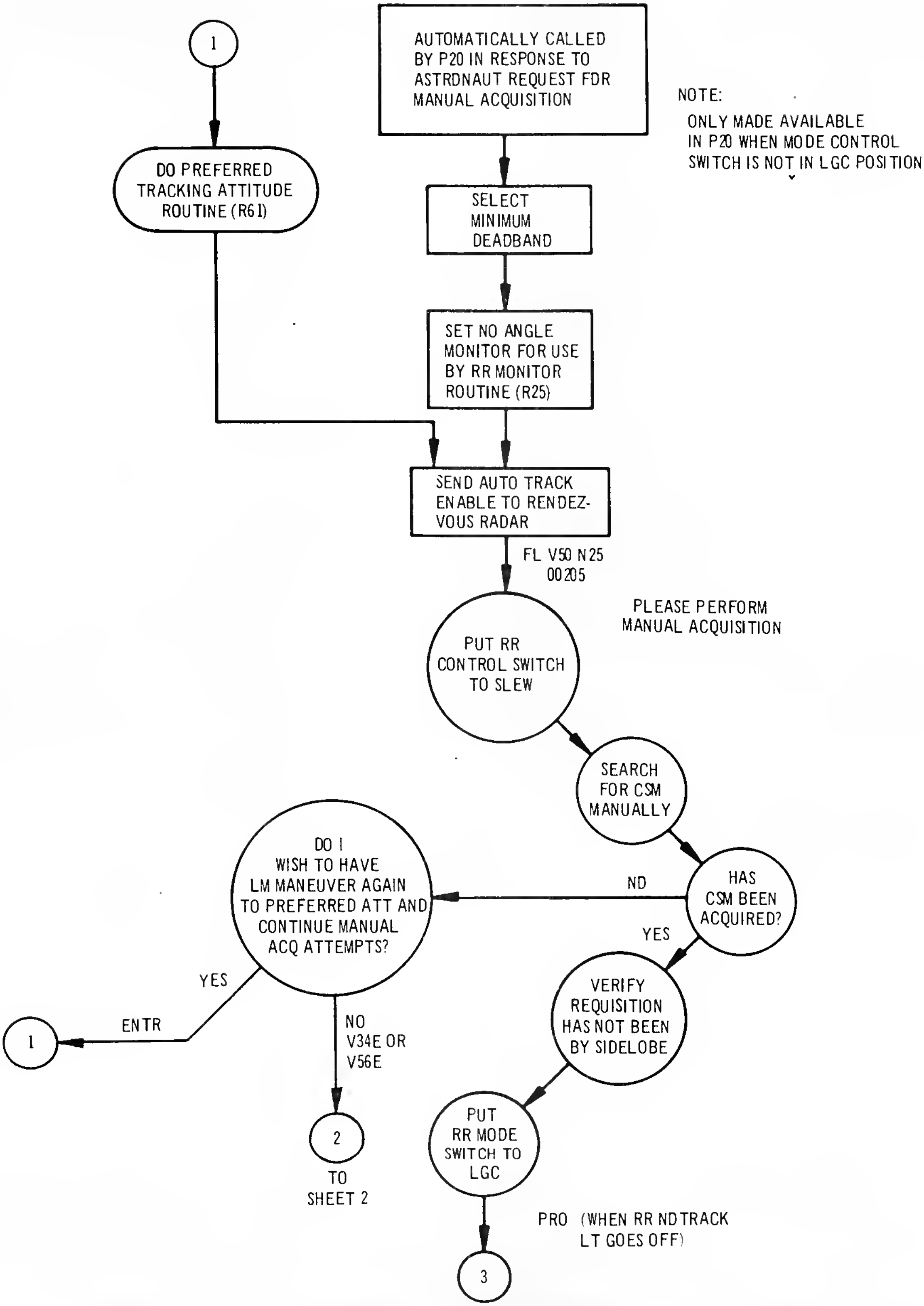


Figure 4.3.1-10. RR Manual Acquisition Routine (LM R23) (Sheet 1 of 2)

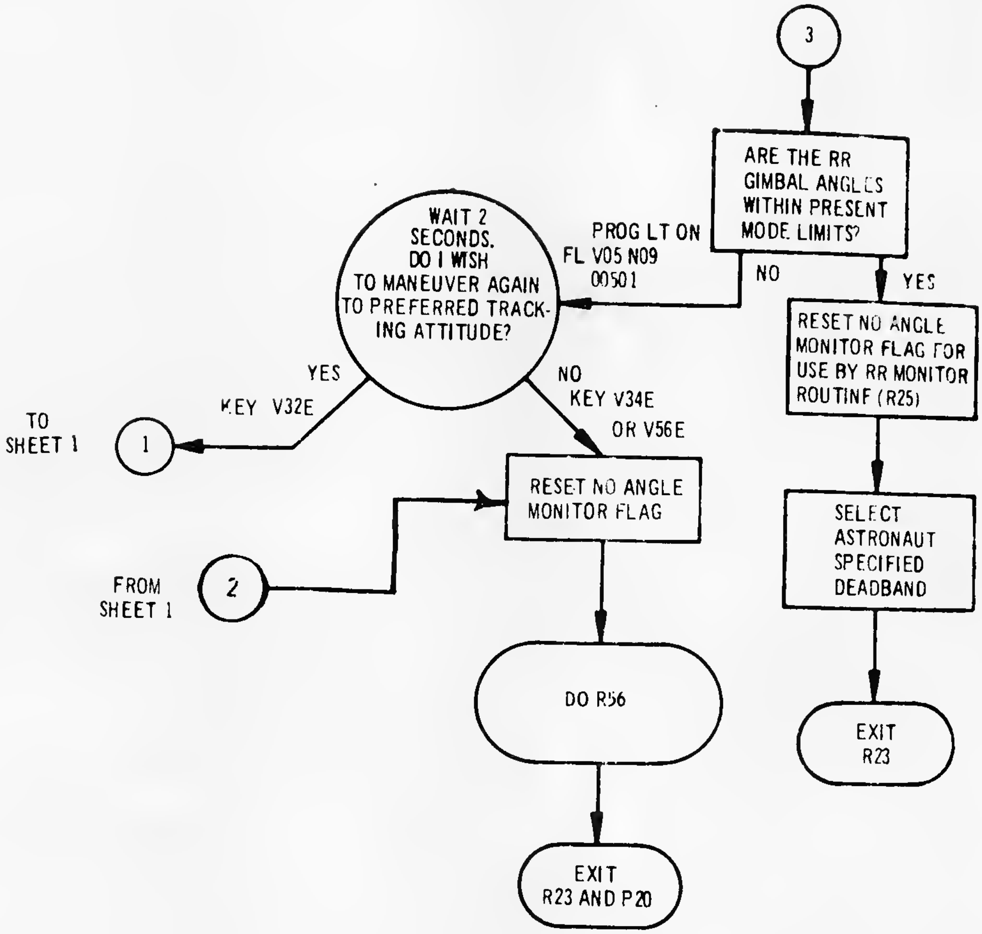


Figure 4. 3. 1-10. RR Manual Acquisition Routine (LM R23)
(Sheet 2 of 2)

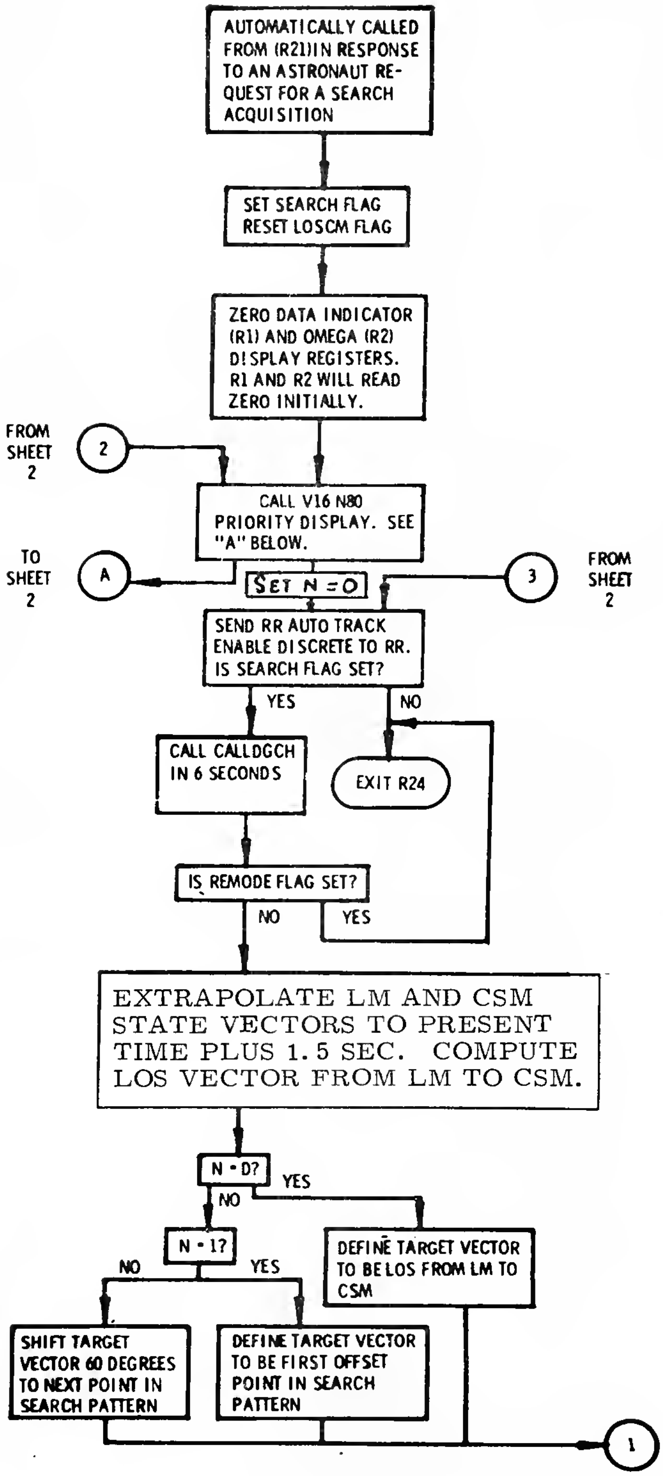


Figure 4.3.1-11. RR Search Mode (LM R24)
(Sheet 1 of 2)

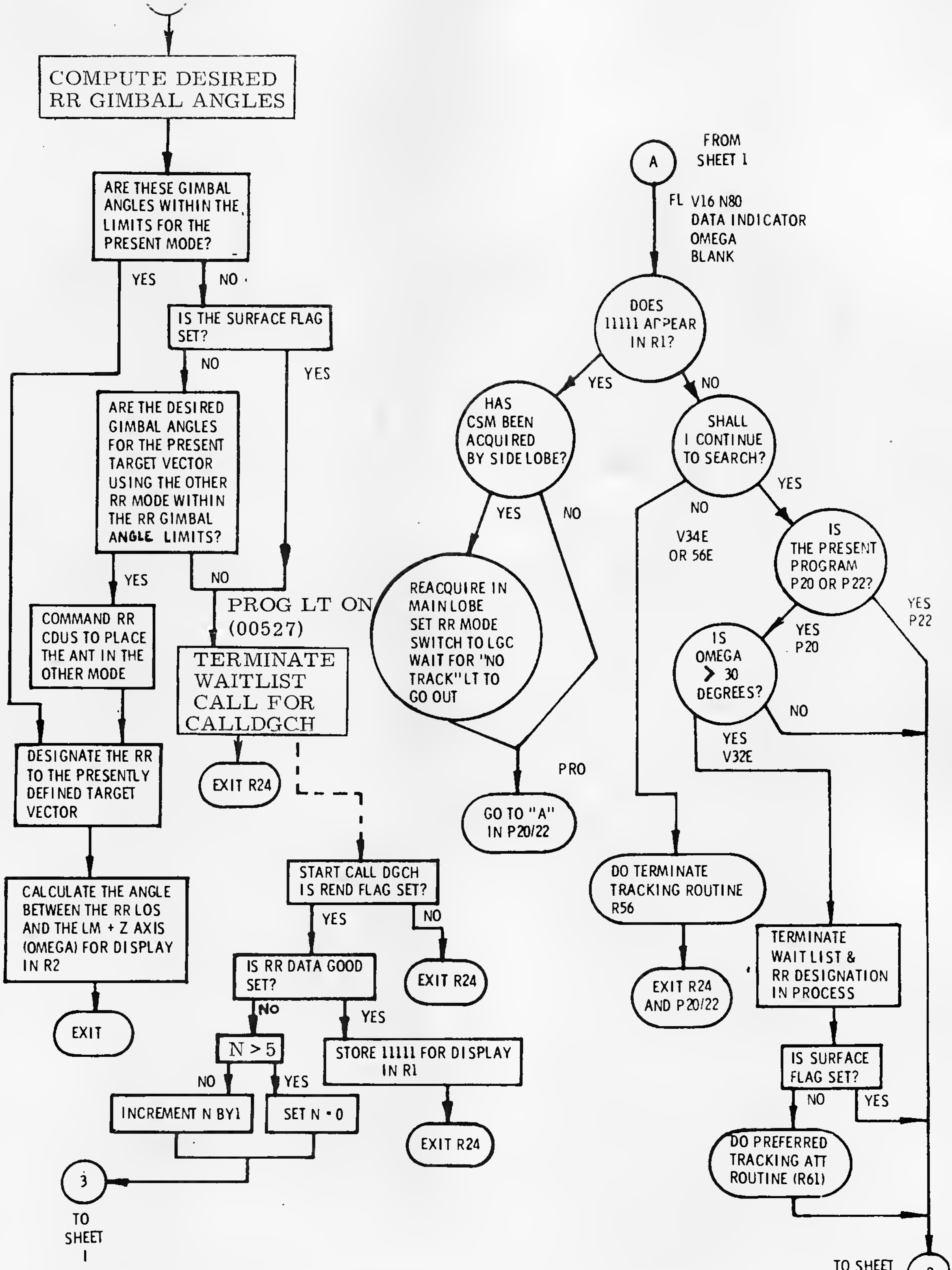


Figure 4.3.1-11. RR Search Mode (LM R24) (Sheet 2 of 2)

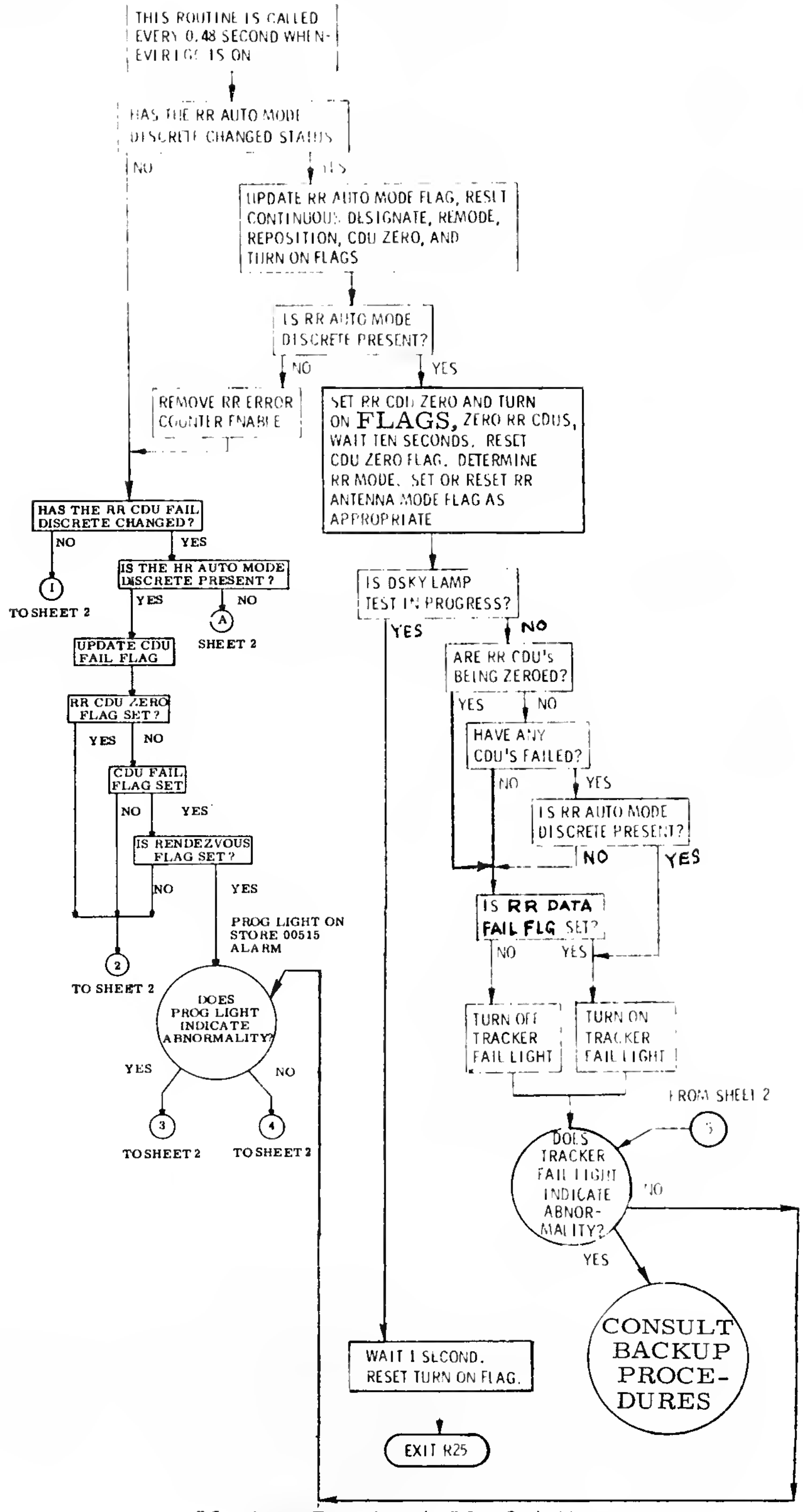


Figure 4.3.1-12. Monitor Routine (LM R25) (Sheet 1 of 2)

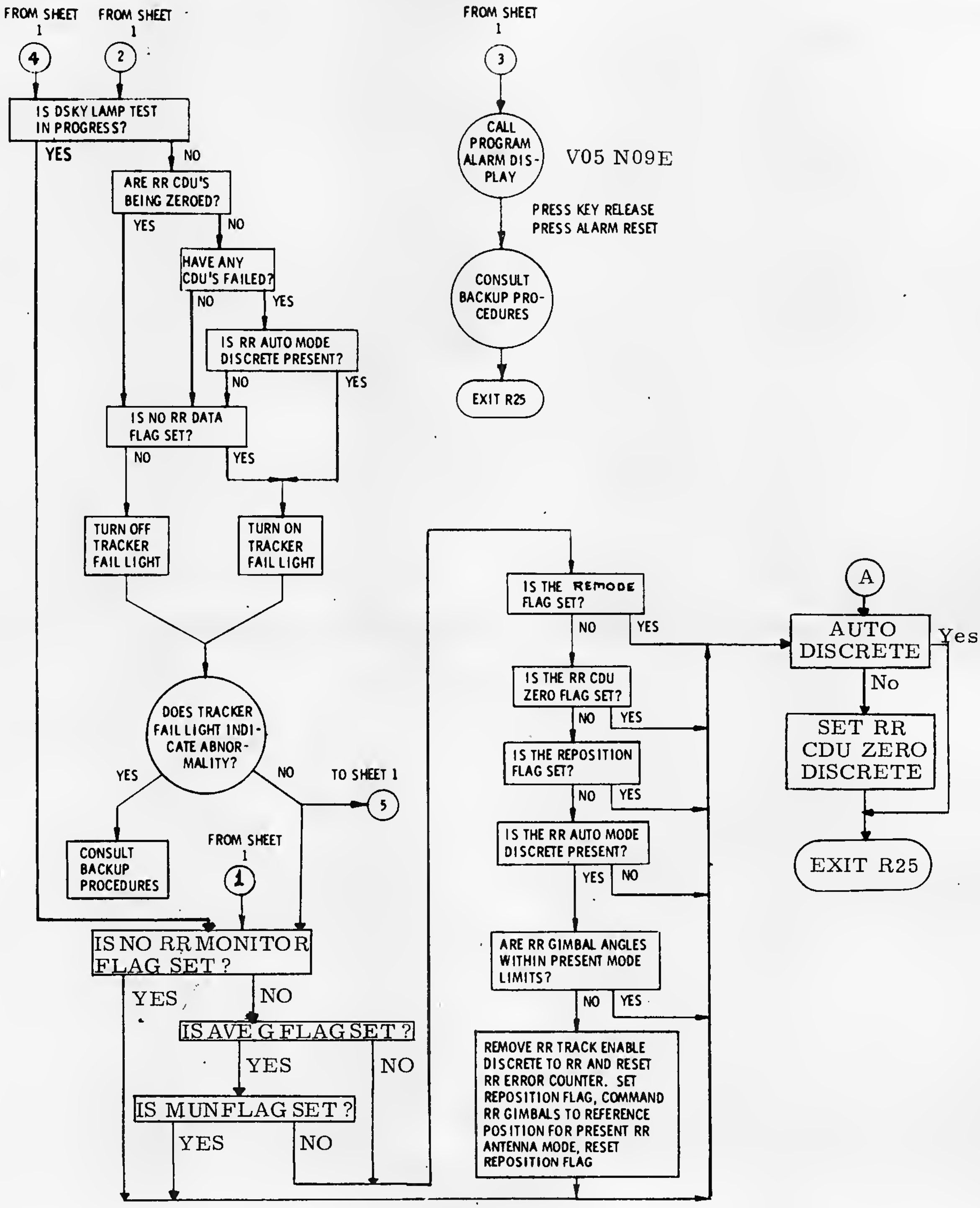


Figure 4.3.1-12. Monitor Routine (LM R25) (Sheet 2 of 2)

positions (dependent upon RR antenna mode). If the RR auto mode discrete changes status, R25 sets various flags ensuring proper initiation or termination of various radar control functions within the LGC. When the RR is first put in the auto mode, R25 zeros the RR CDUs, determines the present RR antenna mode, and updates the TRACKER fail light. When the RR auto mode discrete is removed by the RR, R25 removes the RR Error Counter Enable from the RR CDUs in order to ensure no commands are being sent to the RR gyros. Alarm code 00515 indicates the RR CDU fail discrete is present. If the RR auto mode discrete is not present, the RR CDU zero discrete is set to inhibit RR CDU counter increments.

4.3.1.4.9 Terminate Tracking Routine (LM R56).—This routine is selected by keying in VERB 56 ENTR or VERB 34 ENTR in response to any flashing display in P20 (except VERB 06 NOUN 49). The routine terminates P20 if P20 is running in conjunction with another program. Otherwise, R56 selects R00 to exit P20. (Refer to Figure 4.3.1-13.)

4.3.1.4.10 Attitude Maneuver Routine (LM R60).—This routine maneuvers the LM to an attitude specified by the program in process. (See Figure 4.3.1-14.) This maneuver can be performed either automatically by the PGNCS or manually, with an optional final automatic PGNCS-controlled trim maneuver, and is monitored on the FDAI. R60 can be called by R61 or R65.

4.3.1.4.11 Preferred Tracking Attitude Routine (LM R61).—This routine is automatically called by P20, R22, R23, and R24. R61 performs a single automatic trim maneuver to the preferred tracking attitude if the required maneuver is less than 15 deg; if the maneuver is not less, R61 notifies the crew that an attitude maneuver via R60 is required. (Refer to Figure 4.3.1-15.) By computing and commanding the preferred tracking attitude of the LM (when the LM +Z-axis is aligned along the LOS to the CSM, and the roll attitude about the LM +Z-axis is unconstrained), R61 allows RR tracking of the CSM and CSM tracking of the LM beacon.

4.3.1.4.12 Fine Preferred Tracking Attitude (LM R65).—This routine is automatically called by R22. (See Figure 4.3.1-16.) R65 performs the same functions as R61, except that R65 will perform a series of automatic trim maneuvers rather than a single trim maneuver.

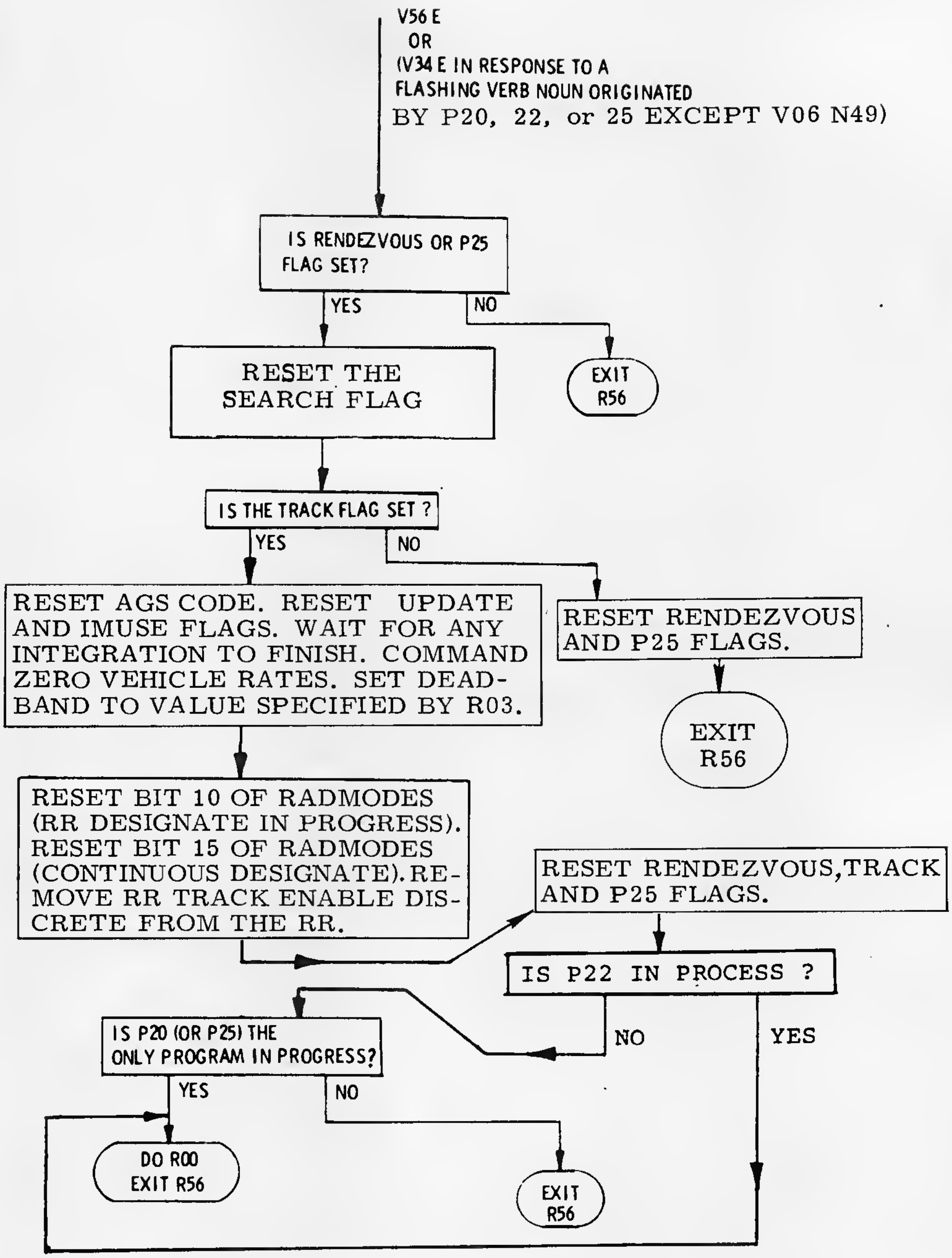


Figure 4.3.1-13. Terminate Tracking Routine (LM R56)

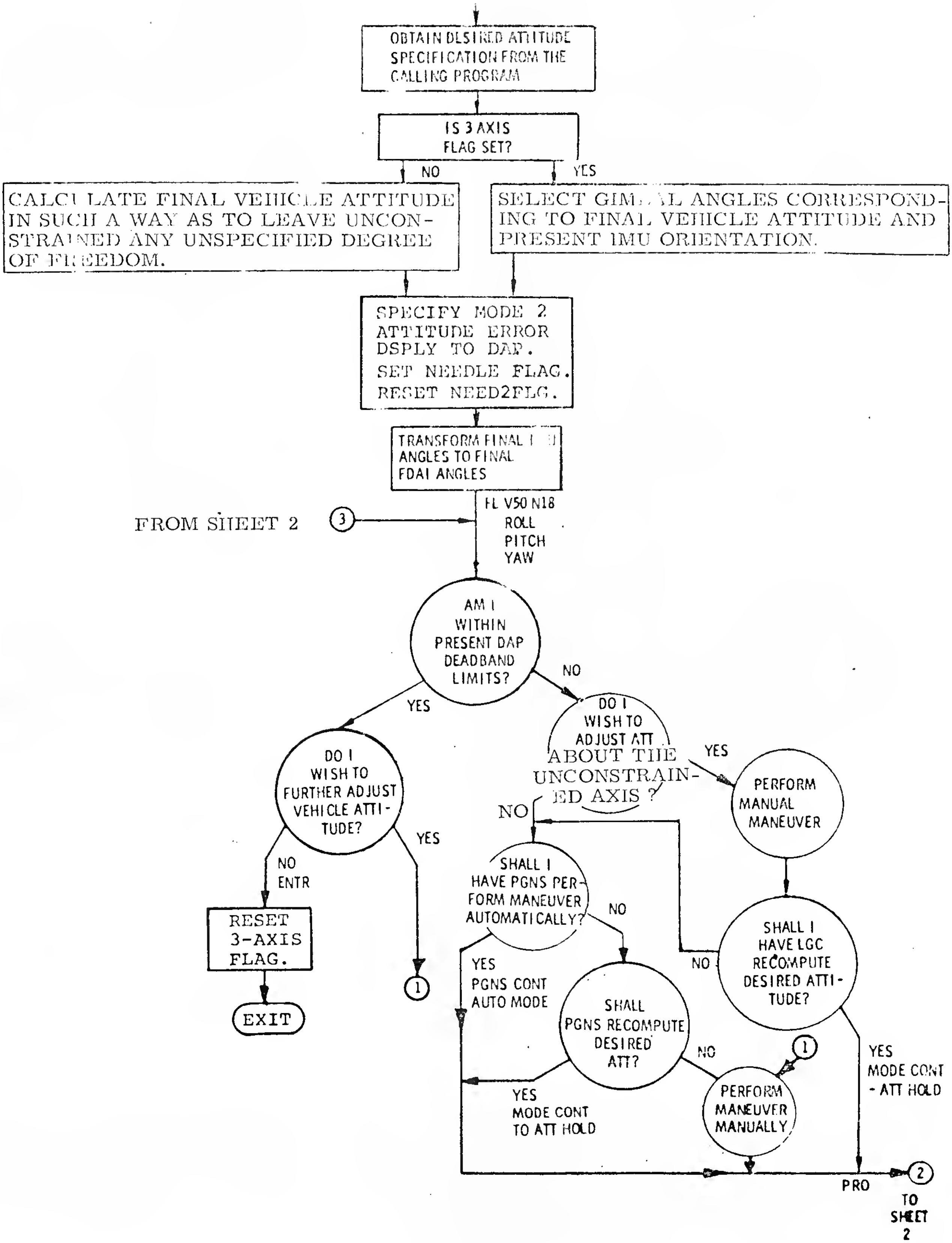


Figure 4.3.1-14. Attitude-maneuver Routine (LM R60) (Sheet 1 of 2)

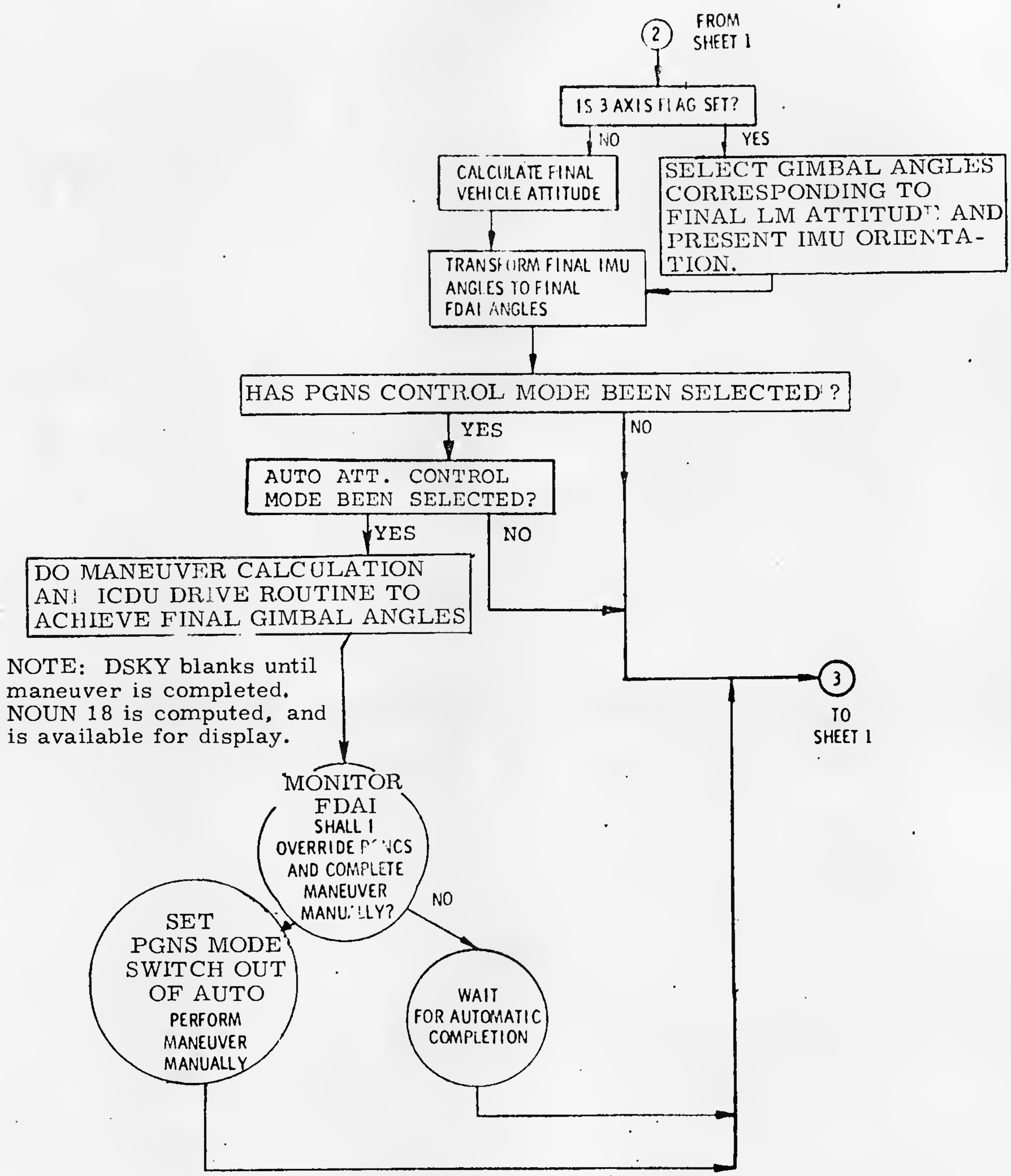


Figure 4.3.1-14. Attitude-maneuver Routine (LM R60) (Sheet 2 of 2)

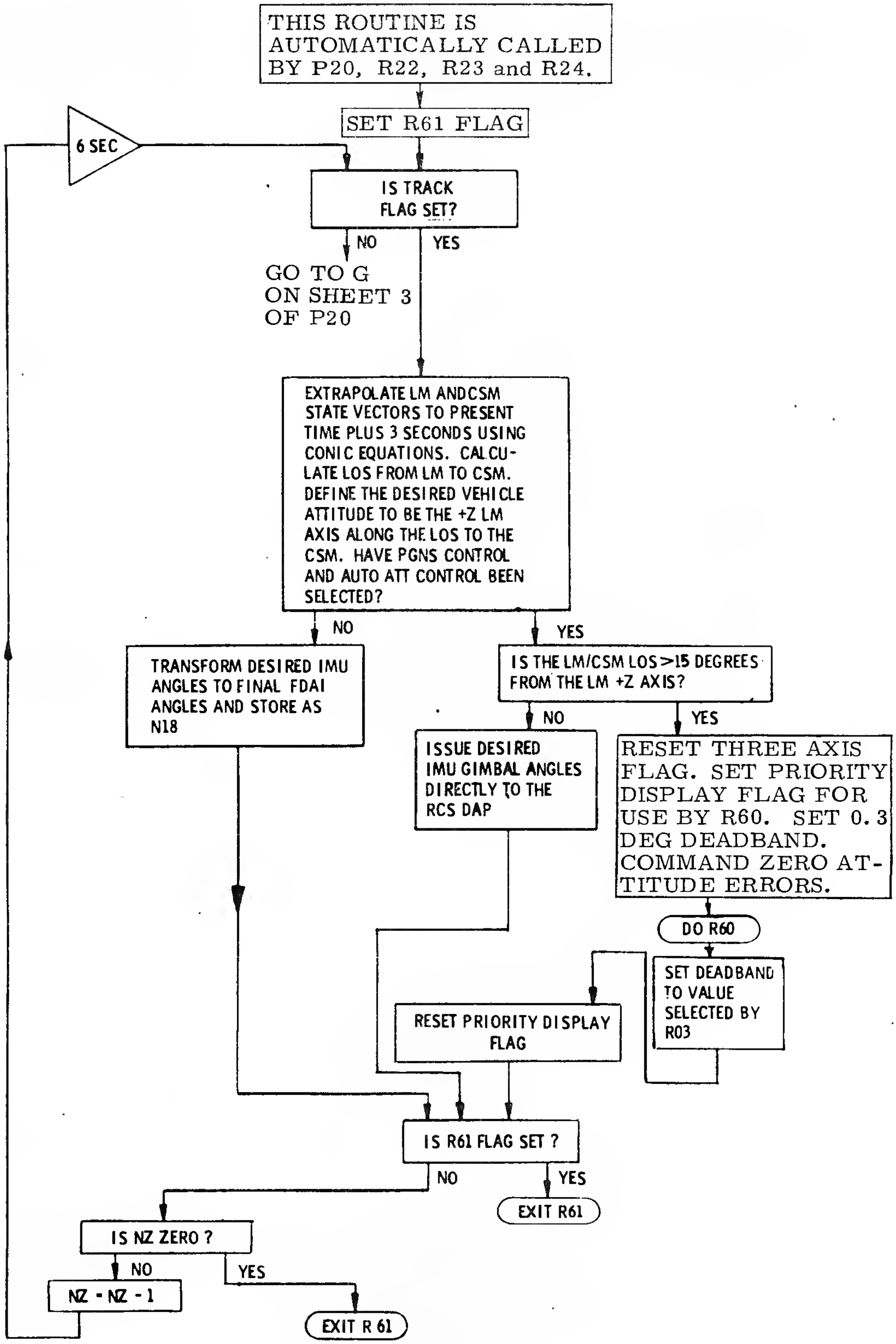


Figure 4.3.1-15. Preferred Tracking Attitude Routine (LM R61)

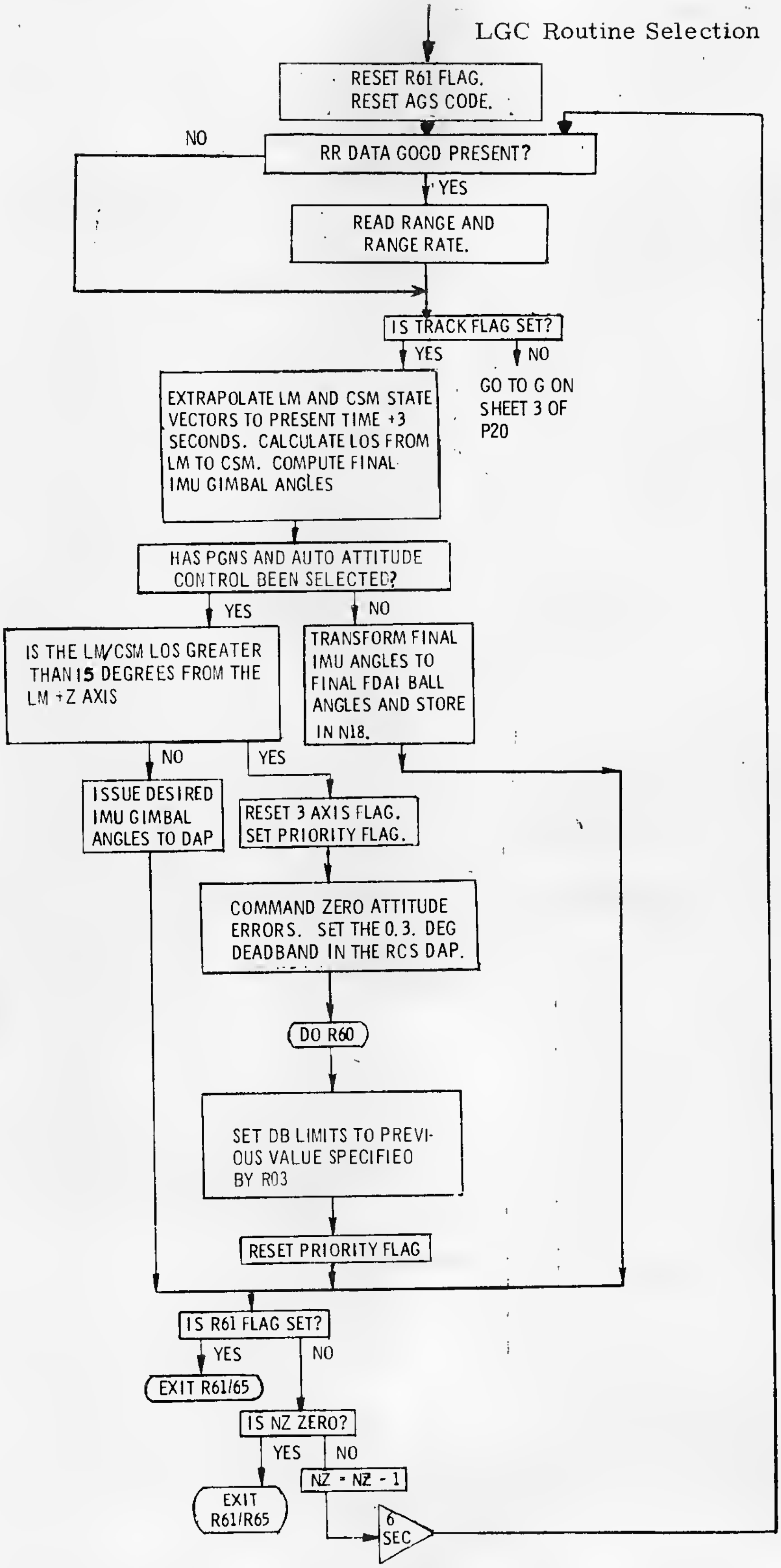


Figure 4.3.1-16. Fine Preferred Tracking Attitude Routine (LM R65)

TABLE 4.3.1-III

RENDEZVOUS NAVIGATION PROGRAM ALARMS (LM P20)

Alarm Code	Cause	Corrective Action
00210	ISS not on	Key V05 N09E to identify abnormality. In response to FL V37, turn on ISS and perform P51.
00220	IMU orientation unknown	Key V05 N09E to identify abnormality In response to FL V37, enter P51.
00501	RR antenna angles are outside angle limits for valid angle measurements	R61 by keying in V32E, unless astronaut keys V56E to exit R23.
00503	R21 unable to acquire CSM	Initiate R24 (key PRO). RR antenna is thus designated in search pattern about the estimated LOS until able to acquire CSM.
00514	RR has been improperly switched out of LGC Mode when it should be supplying automatic measurements for P20	Either terminate P20 or reselect RR Auto Mode.
00515	RR CDU fail discrete present	Zero CDUs by RR mode switch or key in V40 N72. Wait at least 10 sec before clearing alarm. If alarm persists, trouble is serious.
00520	RR interrupt occurred when no request for radar data was made.	Reset alarm.
00525	Delta theta greater than 3 deg.	Key PRO for $\Delta\theta$ display in V06 N05. Accept the correction (PRO), or recycle (V32E) and take a new mark.
00526	Range between LM and CSM greater than 400 n. mi.	Wait until range is less than 400 n. mi., or terminate P20.
00527	Desired RR LOS not within limits of either RR Mode	Vehicle maneuver required via R61.

4.3.1.5 Program Alarms

The following program alarm possibilities are associated with P20. Table 4.3.1-III lists the alarm codes, the causes, and the corrective action required, if any, for the following alarms:

00210 — IMU not operating
00220 — IMU not aligned or IMU orientation unknown
00501 — RR antenna out of present mode limits
00503 — Radar Antenna Designate fail
00514 — RR goes out of Auto Mode while in use
00515 — RR CDU fail discrete present
00520 — RADARUPT not expected at this time
00525 — Delta theta greater than 3 deg
00526 — Estimated range greater than 400 n. mi.
00527 — LOS not within limits of either RR mode

The first two alarms can occur during R02, the IMU Status Check Routine. If the PROG alarm lamp illuminates, the astronaut keys in VERB 05 NOUN 09 ENTR to identify which alarm has been issued. Alarm code 00210 indicates the ISS is not on; alarm code 00220 indicates that the IMU orientation is unknown and must be aligned.

Alarm code 00501 can occur during the operation of R23. This alarm indicates that the RR antenna angles are outside the angle limits for valid angle measurements. The astronaut keys in VERB 32 ENTR to initiate R61, unless he wants to exit the routine via the Terminate Tracking Routine (R56).

Alarm code 00503 will occur if R21 is unable to acquire the CSM. If this alarm occurs, the astronaut should initiate R24 by keying PRO, which causes the RR antenna to be designated in a search pattern about the estimated LOS until it is able to acquire the CSM. Alternatively, a VERB 32 ENTR response will re-initiate R21.

Alarm code 00514 can occur if the RR has been switched out of the LGC Mode when P20 is operating with another program, e.g., P34. The astronaut can either terminate P20 via R56, or reselect the RR Auto Mode by again placing the RR mode control switch in the LGC position and keying PRO.

During the performance of R25, if the RR CDU fail discrete is present, alarm code 00515 will be issued. The astronaut should zero the CDUs by first exiting P20 via

VERB 56 ENTR and then keying in VERB 40 NOUN 72. He should then wait at least 10 sec for completion of CDU zeroing before clearing the alarm. If the alarm persists, use of the RR is lost to the LGC and abort or backup procedures must be considered.

Alarm code 00520 indicates a radar interrupt occurred when no request for radar data was made. The astronaut should ignore alarm code 00520 unless it persists, indicating an LGC hardware problem.

If delta theta ($\Delta\theta$ is the difference between the RR indicated LOS and the state vector indicated LOS) is greater than 3 deg during the Data Read Routine (R22), alarm code 00525 will be issued. Keying in PRO causes $\Delta\theta$ to be displayed via VERB 06 NOUN 05. The astronaut can either accept the correction by keying in PRO, or he can recycle and take a new mark.

At the beginning of P20, when the range between the LM and the CSM is computed, alarm code 00526 will be issued if the range is greater than 400 n. mi. The astronaut can either wait until the range is less than 400 n. mi. and proceed with P20 or he can exit P20 at this time via R56.

During the operation of R24, alarm code 00527 may occur, indicating that the desired RR LOS is not within the limits of either RR mode and, therefore, that a vehicle maneuver is required. The astronaut should then initiate R61 by keying in VERB 32 ENTR.

4.3.1.6 Restrictions and Limitations

The primary concern in the Rendezvous Navigation Program (P20) is the estimated relative position and velocity of one orbiting vehicle with respect to another. P20 solves for the inertial state vector of one vehicle and assumes the other vehicle's state vector to be good. The relative state vector can then be computed by differencing the inertial state vectors. To compensate for measuring uncertainties that exist in solving for this estimated relative state vector, the following is used: a statistical weighting matrix (W-matrix) and an a-priori sensor variance (for determining how much emphasis is to be given to the measured data in updating the state vector and how much is to be given to the current estimate). Refer to subsection 4.1, "Introduction to Coasting Flight Navigation," and to paragraph 4.2.1.

4.3.1.7 Program Coordination and Procedures

The vehicle position and velocity information obtained with P20 provides the basis for the rendezvous targeting programs, P32, P33, P34, P35, and their P70 complements. Once P20 is initiated at the beginning of rendezvous, and radar lock is obtained, RR marks are processed at one-minute intervals between, and if necessary during, the targeting computations. P20 runs in the background simultaneously with the targeting routines. Radar track is broken each time a maneuver to a burn attitude is necessary and updating is inhibited while the actual targeting computations are performed. However, flashing VERB 16 NOUN 45 displays are provided at key points in each targeting program to display the number of RR marks taken at that point. If the number of marks taken is insufficient for proper targeting, the astronaut need only pause at the flashing 1645 display and P20 will resume updating at the one-mark-per-minute rate. When the requisite number of updates has occurred, the targeting computation can be resumed.

Another factor for crew consideration when P20 is running in the background of a targeting program, is that of P20 priority displays. The priority displays in P20 are Verb 50 Noun 18, Verb 05 Noun 09 (with alarms 00501, 00503, 00514, and 00525), Verb 06 Noun 05, Verb 16 Noun 80, Verb 50 Noun 72, and Verb 06 Noun 49. When the LGC attempts to display a priority display, a DSKY light will be illuminated. The light is reset when the astronaut responds to the display by keying PRO, Verb 33 ENTR, Verb 32 ENTR, Verb 34 ENTR, Verb 37 ENTR xx ENTR, Verb 36 ENTR, or Verb 56 ENTR.

4.3.1.8 Restarts

P20 is restart-protected. Should a hardware restart occur, no crew action is required. The astronaut will note, however, that if a restart occurs after lock-on is achieved and tracking is taking place, P20 will automatically re-acquire the CSM and continue tracking. Thus, he would see the VERB 50 NOUN 72 display again.

4.3.2 P21, Ground-track Determination—LGC

LM P21 is essentially the same as CSM P21, which is used prior to selecting lunar landmarks during orbital navigation (P22). During the nominal lunar landing and ascent, the LM position and altitude are known sufficiently not to require use of P21. Consequently, P21 LM would be used only in the unlikely case of an abort due to communications loss.

The program can be used in both earth and lunar orbit to determine the latitude, longitude, and altitude of either the LM or CSM at a time, GET, specified by the astronaut. Using the coordinate information thus obtained, landmarks suitable for marktaking in P22 orbital navigation can be chosen from maps of the lunar or terrestrial surface.

In earth or lunar orbit, P21 can be used to integrate either vehicle's state vector to a desired future time (as it is used with ground track determination); then, when the precision integration computation is finished, VERB 06 NOUN 91 can be keyed in to obtain a display of altitude, velocity, and flight-path angle of the vehicle trajectory extrapolated to the specified time.

4.3.2.1 Ground-track Determination Procedures

Table 4.3.2-I lists the displays that occur in P21. Figure 4.3.2-1 is the program flowchart.

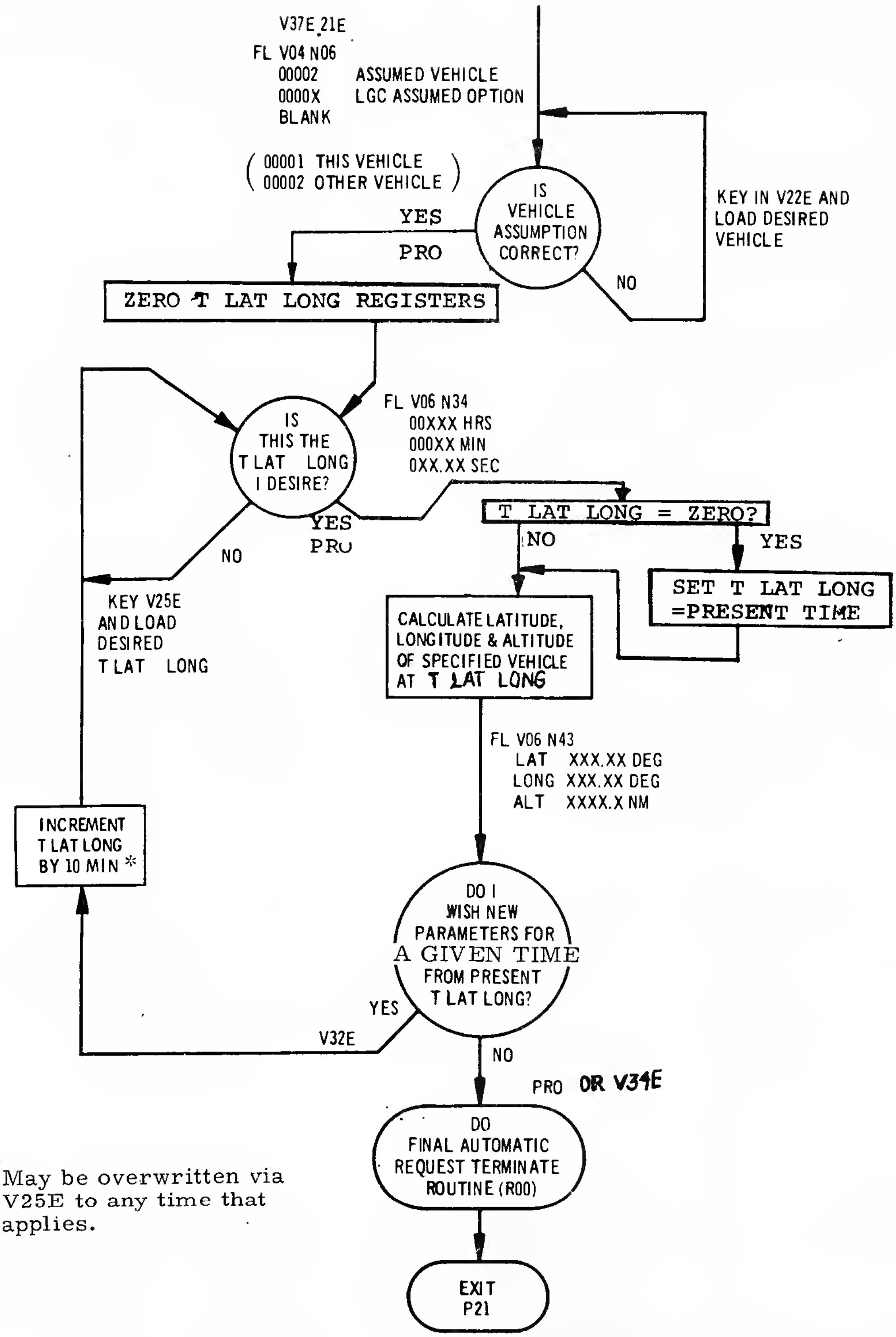
When the astronaut enters P21 via VERB 37, the program displays a 00001 code in R2, indicating the coordinates desired are for this vehicle. If so, the astronaut confirms by keying PRO. If not, the astronaut keys in VERB 22 ENTR, loads 00002 in R2, indicating the other vehicle, and then keys PRO. A flashing VERB 06 NOUN 34 display then appears with R1, R2 and R3 equal to zero. If the astronaut wants the latitude, longitude and altitude for the present time, he can key PRO. If he wants the information for another T LAT LONG, he can key in VERB 25 ENTR, load the desired GET in R1, R2 and R3, and then key PRO. (Refer to Table 4.3.2-I.)

The LGC extrapolates the desired vehicle state vector to T LAT LONG using precision integration, computes the corresponding altitude, and displays the result in the flashing VERB 06 NOUN 43 display. A PRO response to the latitude, longitude, and altitude display terminates P21; a VERB 32 ENTR (recycle) response causes the program to increment the previous GET by 10 minutes and return to the flashing VERB 06 NOUN 34 to display it. A PRO will then recompute the vehicle coordinates for the

TABLE 4.3.2-I

P21 (LM) GROUND-TRACK DETERMINATION PROCEDURES

DSKY	Register	Comments
V37 E21 E	DSKY P21	Only requirement for P21 is an up-to-date state vector. ISS not required.
FL V04 N06	R1 00002 R2 00001 R3 Blank	Vehicle code in R1 00002 R2 00001 indicates this vehicle. May be changed to R2 00002 to indicate other vchicle. PRO if correct; V22E will permit R2 to be changed.
FL V06 N34	R1 ooxxx. hr R2 oooxx. min R3 oxx.xx sec	Request load GET for lat-long desired in hours, minutes and seconds to nearest 0.01 sec. For present time set R1, R2, and R3 to all zeros. PRO to compute LAT-LONG for specified GET; key V25E to change time.
FL V06 N43	R1 xxx.xx deg R2 xxx.xx deg R3 xxxx.x n.mi.	Program displays vehicle latitude and longitude in degrees to nearest 0.01 deg in R1 and R2 (+ is North and +East, respectively) for specified GET. R3 contains altitude in nautical miles to nearest 0.1 n.mi. measured from launch pad radius (earth) or latest landing site radius (moon). V32E increments T LAT LONG GET initially specified by 10 minutes, recycles to V06 N34 display. T LAT LONG may then be overwritten via V25E to any desired time.
FL V37		PRO terminates P21.
V06 N91E	R1 xxxxxB n.mi. R2 xxxxx. fps R3 xxx.xx deg	Altitude to nearest 10 n.mi. Inertial velocity to nearest 1 fps. Flight path angle to nearest 0.01 degree. This display may be obtained in P21 any time after integration is complete.



*May be overwritten via V25E to any time that applies.

Figure 4.3.2-1. Ground-track Determination Program (LM P21)

new, 10-minute later T LAT LONG. Successively keying VERB 32 ENTR and PRO produces a series of latitude, longitude, and altitude values for successive 10-minute intervals, one for each VERB 32 ENTR recycle keyed in.

4.3.2.2 Orbital Parameters

The astronaut can key in the VERB 06 NOUN 91 orbital parameters display during P21 after the precision integration extrapolation is complete (when the LGC CMPTR ACTY light goes out) and obtain vehicle altitude h, velocity v, and flight-path angle for the time specified in NOUN 34. This display can be used after DOI, before CSI, and during abort trajectories to monitor orbital parameters. Alternatively, the VERB 82 orbital parameters display can be called after the latitude-longitude-altitude display; i.e., after state-vector integration is complete. VERB 82 displays apogee and perigee height and time of free fall; this trajectory information supplements NOUN 91.

4.3.2.3 Alarms

The only alarm in P21 is the 20430 acceleration-overflow-in-integration alarm, which occurs when a register summing acceleration overflows during orbital integration. The 20430 alarm is always triggered well below the lunar surface. Consequently, although a 20430 alarm invariably signals an impact trajectory, the converse is not true; i.e., the absence of a 20430 alarm does not guarantee a trajectory to be safe.

4.3.2.4 Restrictions and Limitations

The only use presently envisioned for P21 LM is during off-nominal aborts. For reasons stated above, the 20430 alarm should never be depended upon as a GO/NO-GO test for impact trajectory. The orbital parameters (VERB 82), rendezvous parameters (VERB 83) and the VERB 06 NOUN 91 displays must be used instead. (Refer to Table 4.3.2-I.)

4.3.2.5 Restarts

Should a restart occur during P21, the program would return to the last flashing display.

4.3.3 P22, Lunar-surface Navigation—LGC

The Lunar-surface Navigation Program is used to perform the following:

a. To control the rendezvous radar (RR) to acquire and track the CSM while the LM is on the lunar surface
b. To update the CSM state vector on the basis of range and range-rate tracking data from the RR
c. To track the CSM without updating its onboard state vector while the resulting RR data are downlinked for use in ground computation of the CSM state vector.

Currently authorized use of P22 includes LGC control of the RR to acquire, track and obtain range and range-rate data in the no-update mode. That is, data are not processed onboard and incorporated to update the CSM state (b above), but are downlinked (a and c). In case of communication failure, a plane-change option in P22 can be used to compensate the onboard CSM state for precession of the CSM orbit, but no updates will be made.

Figure 4.3.3-1 shows the significant events in a typical Lunar-surface Navigation timeline plotted on a diagram of LM-CSM geometry during a 60-n. mi. orbital overpass. Times are measured from the instant the CSM comes within 400 n. mi. of the landing site. (Range is computed by the program using the onboard estimate of the CSM state vector. Ranges and times are, therefore, nominal, i.e., uncertain by 2 to 3 n. mi. and 2 to 3 seconds.)

Table 4.3.3-I gives the time, information displayed, R, R-dot, θ (elevation angle), and $\dot{\theta}$ for the key events in the P22 sequence.

P22 operation occurs in three consecutive phases: the pre-designate, designate and measurement phases. During the pre-designate phase, the program computes an RR acquisition angle and drives the RR antenna to it to await the CSM. At the predicted CSM arrival time, the LGC designates the RR, causing it to track the CSM estimated position, while the RR acquires (i.e., achieves auto-track of the radio frequency return from the CSM transponder). This effectively fulfills purpose a, above.

The designate phase ends and the measurement phase begins when the RR achieves lock and issues the data-good discrete. (Acquisition may occur as quickly as 5 sec but must occur within 45 sec, or a designate fail alarm is returned.) After RR

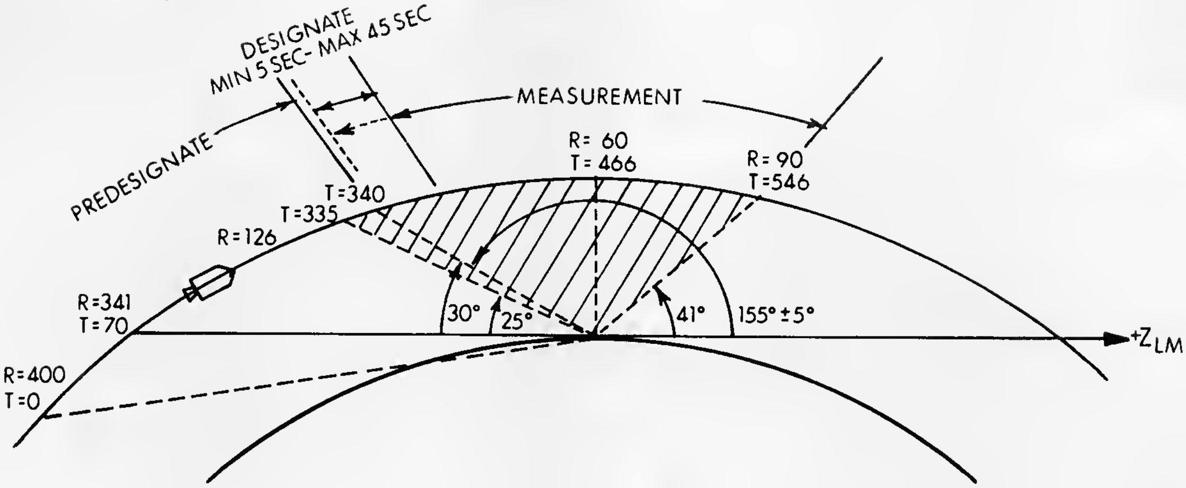


Figure 4. 3. 3-1. Typical Lunar-surface Navigation Geometry, Event Times and Ranges

TABLE 4. 3. 3-I

LUNAR-SURFACE NAVIGATION EVENT TIMES, DISPLAYS AND PARAMETERS (LM P22)

T (sec)	Event	Display	R (n. mi.)	$\dot{R}$ (fps)	θ (deg)	$\dot{\theta}$ (deg/ sec)
-20	CSM R > 400 n.mi.	V16 N54 if in P22	>400			
0	CSM at 400 n. mi., enter P22	(V83 optional)	400			
15	R21 designates RR to center Mode 2	V16 N56, X-pointers				
70	CSM on horizon		341	-5021	0	0.05
110	R26 designates RR to Mode 2 limit	V16 N56, X-pointers				
335	CSM enters Mode 2 limit	X-pointers, V16 N56	126	-4551	25	0.21
340	RR acquires CSM	No track light				
466	CSM overhead	V85, V16 N56	60	0	90	0.84
546	CSM out of limits	NO TRACK light, X-pointers	90	+3867	41	0.38

lock, the program processes radar range and range-rate data onboard (b) or downlinks it (c) for ground computation, until the farther limit of the marktaking window is reached.

RR Angle Display Coordinates

The shaded area in Figure 4.3.3-1 corresponds to the RR Mode 2 shaft limits shown in Figure 4.3.3-2 and in Figure 4.3.3-3. RR antenna direction is often specified by the LOS elevation angle above the horizontal (θ, in Table 4.3.3-I) but RR shaft and trunnion angles are displayed according to two different conventions.

The CSM approaches from the $-Z_{LM}$ direction and Figure 4.3.3-1 shows RR LOS angles measured from the $+Z_{LM}$-axis as displayed in VERB 16 NOUN 56 obtained via VERB 85. The RR Mode 2 LOS limits using VERB 85 range between +155 deg at the Mode 2 acquisition limit (25 deg elevation) and 41 deg at the far bound of Mode 2. Figure 4.3.3-3 shows the corresponding RR shaft angles as displayed in VERB 16 NOUN 72. The RR reference position is boresighted down the $+Z_{LM}$ axis, so the RR trunnion must turn 180 deg and then the shaft must rotate -25 deg to attain the +25 deg LOS elevation angle at the acquisition mode limit. The shaft angles are displayed positive in VERB 16 NOUN 72 and, therefore, range from 330 deg, ±5 deg at acquisition, to +220 deg at the far mode limit. The Mode 2 center is 180-deg trunnion, and 270-deg shaft in VERB 16 NOUN 72; 0-deg trunnion and 90-deg shaft in VERB 85. (Refer to Figure 4.3.3-3.)

4.3.3.1 Geometry and Timing

Table 4.3.3-I gives the times, measured in seconds from 400 n. mi., for the significant events in P22 when the LM is on the lunar surface and the CSM is orbiting at 60 n. mi.

Significant events in the acquisition sequence noted in Table 4.3.3-I are as follows:

a. The point, approximately 7-3/4 minutes (466 sec) before the zenith, where the CSM comes within the 400-n. mi. maximum range of the LM RR(T = 0 when R = 400 n. mi.). Initiation of pre-designate when the CSM is farther than 400 n. mi. causes a VERB 16 NOUN 54 display.
b. The point, 70 seconds later, where the CSM crosses the landing site local horizontal (simultaneously with the spacecraft +Z-axis if the spacecraft is level, otherwise modified by the angle the spacecraft Z-axis is inclined to the landing site horizontal).

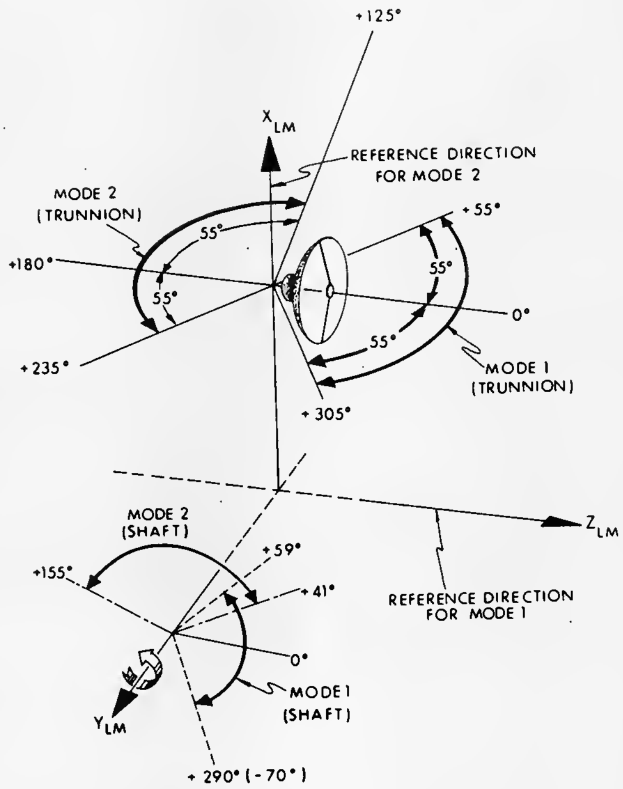


Figure 4.3.3-2. RR Antenna Shaft and Trunnion LOS Tracking Regions

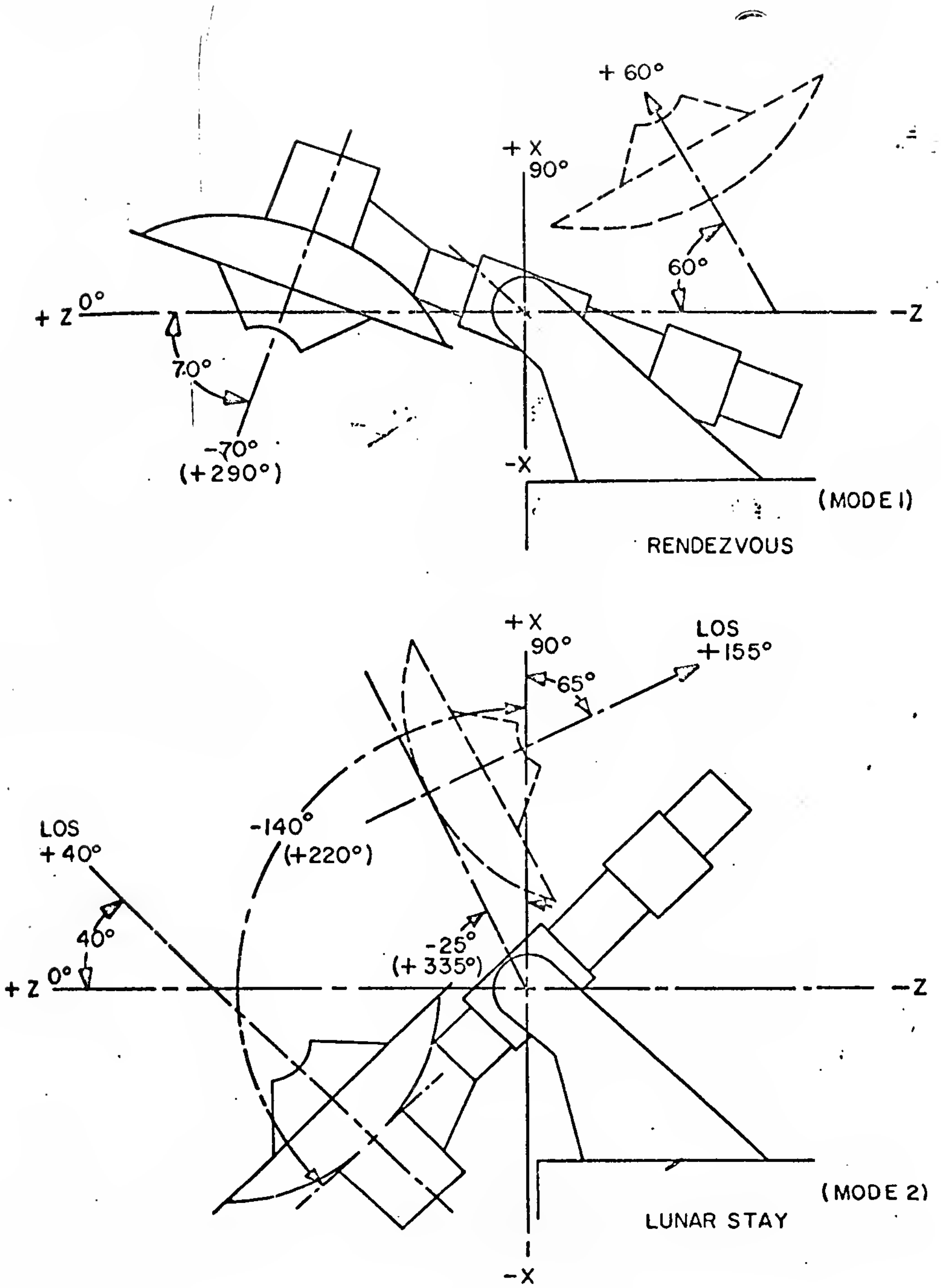


Figure 4. 3. 3-3. RR Antenna Modes of Operation

c. The time when the RR is designated just inside the Mode 2 limit.

d. The shaft angle at which the CSM enters the RR Mode 2 coverage, nominally 155 deg and 335 sec after T = 0, also varies by the angle between the spacecraft Z-axis and the local horizontal. A 5-deg tilt of the spacecraft Z-axis toward the CSM will cause acquisition to occur 23 n. mi. farther and 28 seconds earlier than nominal, so that minor variations in spacecraft attitude may have significant effects on the timing of acquisition and marktaking windows. Procedures for designating the RR, and monitoring the track acquisition and lock-up phases are discussed below.

The designate phase lasts 45 seconds, during which the LGC points the RR at the moving CSM while the radar attempts to automatically track and lock on the return from the CSM transponder. The CSM enters the RR Mode 2 antenna limit 131 seconds before the zenith and exits 80 seconds after, requiring a total of 211 seconds to traverse the entire Mode 2 marktaking window. Ten to fifteen seconds are required for the RR to obtain lock, and up to ten seconds to provide a margin at the acquisition window. Thirteen seconds are required to process each set of mark data in the onboard update case.

In the no-update case, range and range-rate marks are obtained from the RR approximately every 3-1/2 seconds. Forty to 60 marks are, therefore, obtained and processed per pass—using downlink and ground processing—compared to the 10 to 15 that would be processed onboard if onboard updates were used.

4.3.3.2 Mission Situation and Operational Context

In the no-update case, P22 is used once on the first CSM orbital overpass after LM touchdown and again one or more orbits before launch to ensure that the launch site lies in the CSM orbital plane. The CSM Orbital Plane Change Routine in P22, at the astronaut's option, will compute the amount of the plane change required to rotate the estimated CSM orbital plane so that it contains the landing site. The plane-change option is prescribed, in case of communication loss, to compensate for precession. The plane-change computation requires that the astronaut input the launch time, which establishes the CSM position vector at launch; the CSM position vector is then rotated 90 deg retrograde to fix the point at which the plane change is performed. (See Figure 4.3.3-4.)

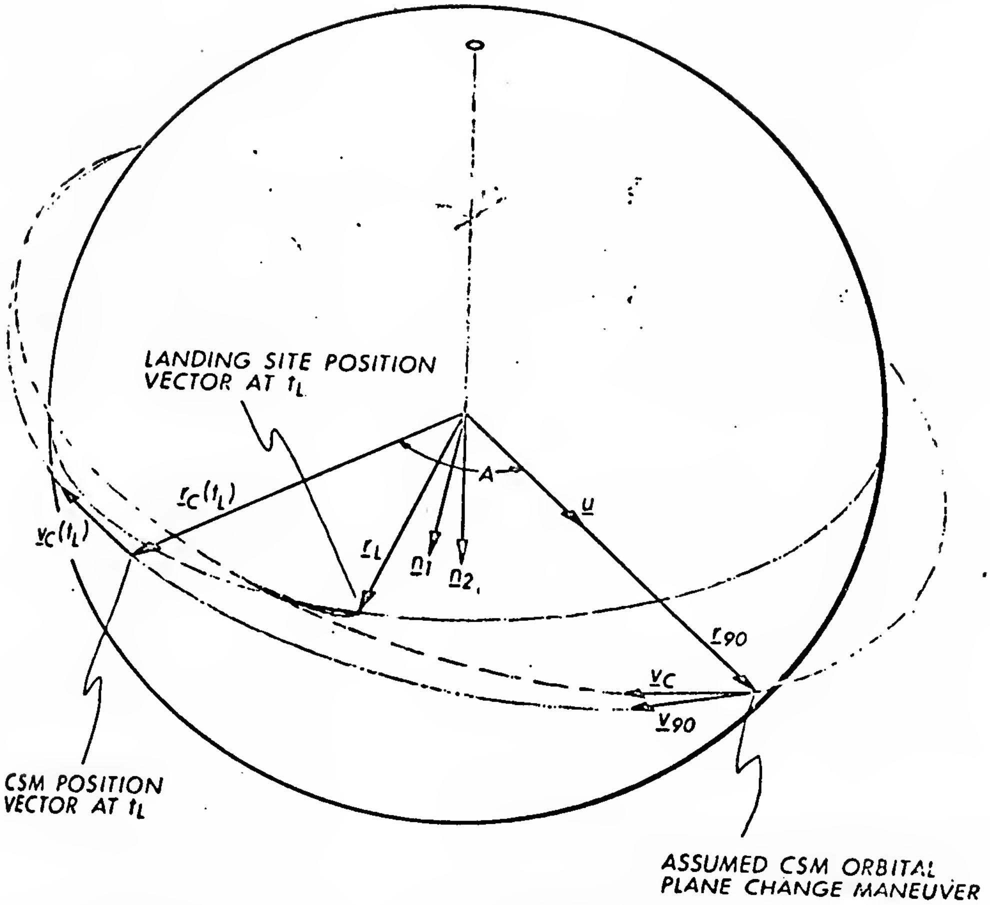


Figure 4.3.3-4. RR Lunar-surface Navigation–CSM Orbital Plane Change Estimation

4.3.3.3 Nominal Operating Sequence

4.3.3.3.1 Acquisition.—After the result of the plane change (if any) is incorporated into the CSM state, the program checks the IMU status and conditions a number of flags required subsequently by various subroutines. It then computes the LOS from the LM to the CSM to determine if its range is less than 400 n. mi. If not, the program issues a VERB 16 NOUN 54, with the onboard estimates of range and range rate displayed in R1 and R2, and updated approximately every 5 sec until the range is less than 400 n. mi.

When the range is less than 400 n.mi., the program next checks to ensure that the RR auto mode discrete is present (i.e., that the RR mode switch is in the LGC position). If it is not, the program requests, via a VERB 50 NOUN 25 display on the DSKY, that the astronaut switch the radar to LGC. The RR Monitor Routine, R25, is called every 0.48 second, when the LGC is on, by the T4RUPT utility program to monitor the RR auto mode discrete, the RR CDU fail discrete, and the angular excursion of the RR antenna relative to the mode limits. R25 conditions various flags to ensure proper RR functioning when the RR auto mode discrete is first received as a result of placing the RR mode switch in the LGC position. The routine alters the status of these flags appropriately if the switch position is changed. If there is a CDU failure while the RR auto mode discrete is present, R25 turns on the PROG alarm light and the TRACKER fail light (on the DSKY) and stores the CDU fail alarm code (00515).

With the RR in the LGC mode and the RR auto mode discrete present, the program next checks the Track and Rendezvous Flags and performs a precision update of the LM and CSM permanent state vectors immediately before entering the RR Designate Routine, R21. (The time required to cycle through the Kepler subroutine, which is used repeatedly during the designation process, is a function of state vector age.) R21 computes the LOS from the LM to the CSM (LOS_{LC}) and determines if the LOS_{LC} is within the Mode 2 limit. If the LOS_{LC} is outside Mode 2, RR designation and acquisition obviously cannot take place, and program control is transferred to R26, the Pre-Designate Routine. R26 is designed to extrapolate the estimated CSM orbital path until it intercepts the antenna mode limit, thereby determining the vector to which the RR should be designated to achieve earliest possible acquisition. R26 extrapolates the LM onboard estimate of the CSM state vector in 10-second increments from the time R26 is entered (effectively the time when the astronaut keyed his response to the preceding plane-change display). A capability for sixty 10-second increments is provided in R26. Having computed the earliest feasible LOS_{LC} for radar acquisition, R26 designates the RR CDUs continuously to that (static) acquisition

angle until present time equals the predicted T_{LOS}. When $T = T_{LOS}$, R26 returns control to R21, which initiates the actual designation process (LGC-controlled RR tracking of the CSM) during which the RR should acquire, i.e., track and lock-on, the RF return from the CSM transponder.

R21 issues rate commands to the RR proportional to the difference between the current RR LOS and the LOS_{LC} computed for one second ahead. When the RR LOS comes within 1/2 deg of the computed LOS_{LC}, the LGC issues the auto track enable discrete to the RR. R21 continues to designate rate commands to the RR until the data good discrete is received from the RR or until 60 commands have been issued—which requires a maximum of 45 seconds.

The astronaut should have the RR shaft and trunnion angles displayed to him via VERB 85 (VERB 16 NOUN 56), and the shaft and trunnion rates displayed to him by the X-pointer on the RR panel. By monitoring the RR shaft angle in the VERB 16 NOUN 56 display of VERB 85 he can determine when the RR has been driven to the (static) pre-designate angle by R26, and by observing the trunnion rate transient at T_{LOS}, he will obtain an indication of when R21 begins RR designate.

4.3.3.3.2 Rendezvous Radar.—In the nominal case, the SIGNAL STRENGTH meter on the RR panel indicates the presence of an RF return and the NO TRACK light (on the RADAR panel) should go out within 5 to 10 seconds, indicating the presence of the data good discrete.

The data good discrete is issued by the RR when its range-rate loop achieves lock, whereupon its angle-track loop is closed simultaneously. If the RR fails to obtain range-rate lock (data good present) within 45 seconds, a 00503 alarm signifying that RR is unable to acquire is issued. The astronaut can respond by either re-establishing the designate process or initiating RR search. The RR beamwidth (Figure 4.3.3-5) is sufficiently wide (3.3 deg) relative to target position uncertainty, that acquisition should consistently occur early in the designation phase; if it has not occurred after 45 seconds, a gross error in the LGC—CSM state probably exists. This indicates that further designation is useless and the search option response is appropriate.

4.3.3.3.3 Data Read Options: Downlink or Onboard Update.—Upon receipt of the data good discrete, R22, the Data Read Routine, is called; this routine, in turn, calls R20. R20 begins to sample the range and range-rate data supplied by the RR and processed by R22. If the data good discrete is lost, the NO TRACK light (on the RADAR panel) will illuminate.

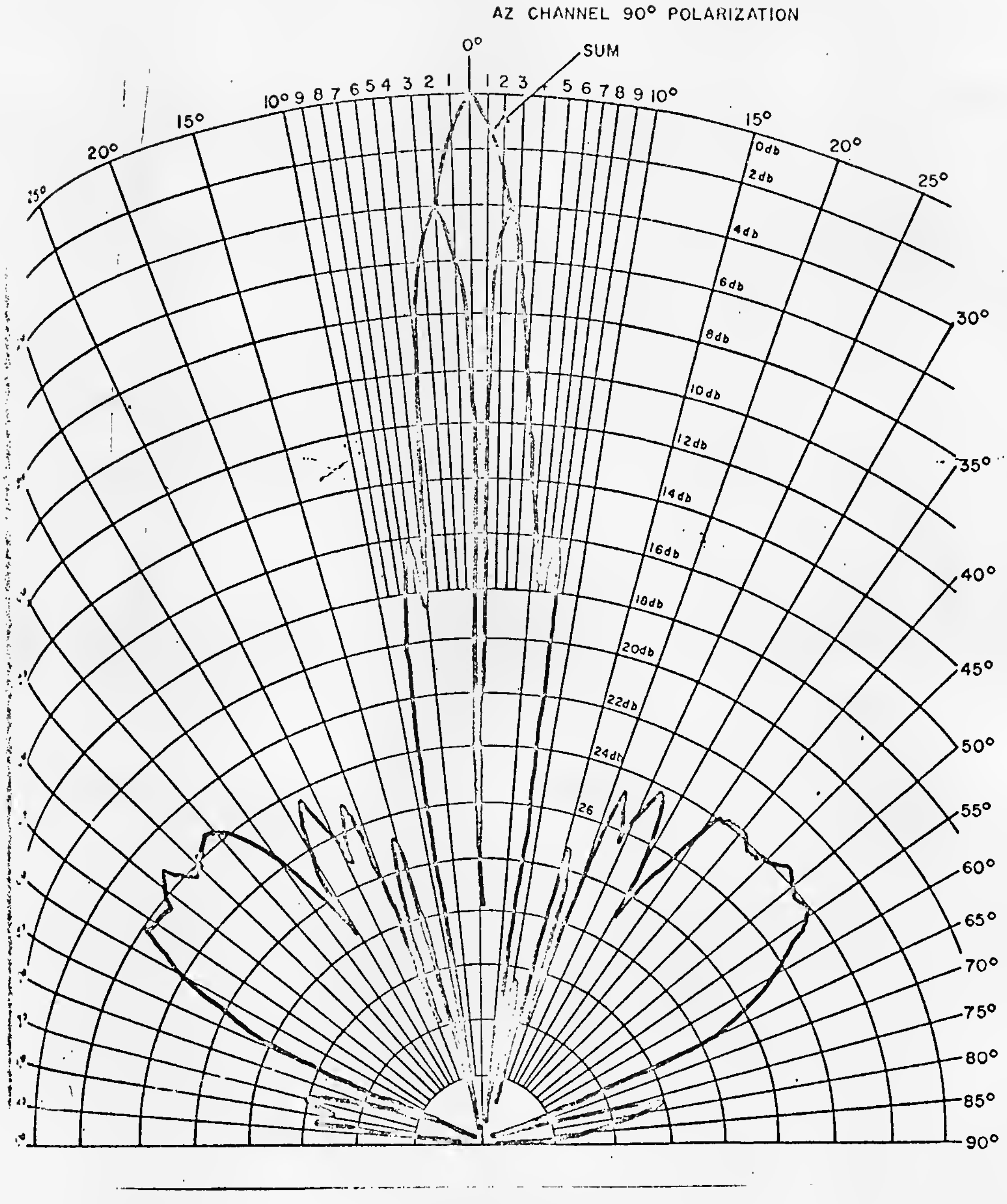


Figure 4.3.3-5. RR Lobe Pattern; Azimuth Channel AA-20

In the no update mode—when VERB 95 ENTR (see Table 4.3.3-IV) has been used to set the No Update flag—a complete set of RR data, consisting of range, range rate, and RR CDU angles, is read approximately every 3.5 seconds. The downlink list cycles every 2 seconds so that 30 or more RR measurements can be incorporated into ground computations on each CSM orbit.

After each RR mark, a 3-deg check is performed in R22; this check determines whether the RR LOS is within 3 deg of the LOS computed from the state vector. A 00525 alarm is displayed if the angular difference is more than 3 deg. The alarm permits the astronaut to verify and correct an RR sidelobe lock condition during rendezvous. However, when navigation marks are being taken, with P22, on the lunar surface, no time is available to correct sidelobe lock and the astronaut should key PRO in response to the 00525 alarm and to the VERB 06 NOUN 05 $\Delta\theta$ display, in both the update and no-update modes. A 2-second priority hold is necessary before the first PRO response to the 00525 alarm and before the PRO to the VERB 06 NOUN 05 display. (Details of the appropriate procedure to follow are discussed in 4.3.3.5, below.)

In the onboard update case, the program performs a threshold test on the range and range-rate component of each RR mark before incorporating the result. If the magnitude of the update is excessive, it is displayed via VERB 06 NOUN 49 to the astronaut for an accept/reject decision. If the magnitude of the update is within limits, it is incorporated automatically. At present, a zero W-matrix is used to ensure no-update operation.

4.3.3.4 Program Operational Details

4.3.3.4.1 P22 Procedures.—Figure 4.3.3-6 is a flowchart showing the sequence of program and DSKY activity in P22. Table 4.3.3-II lists the DSKY displays. In the majority of cases in the initial VERB 04 NOUN 06 display, 00001 is usually loaded in R2. In the no-update use of P22, a good CSM state vector will be uplinked from the ground shortly before liftoff, which will incorporate the result of any plane change. Should a communication loss occur, relatively little time would elapse (2 orbits maximum) before launch. For the essentially equatorial CSM orbits used through APOLLO 14, the change in the plane of the CSM orbit is negligible. For later missions with significant orbital declination, the plane of the CSM orbit will precess and the plane-change option is authorized to compensate.

If a plane change is specified in the flight plan, the corresponding launch time is input by the astronaut and the resulting orbital change is incorporated into the CSM

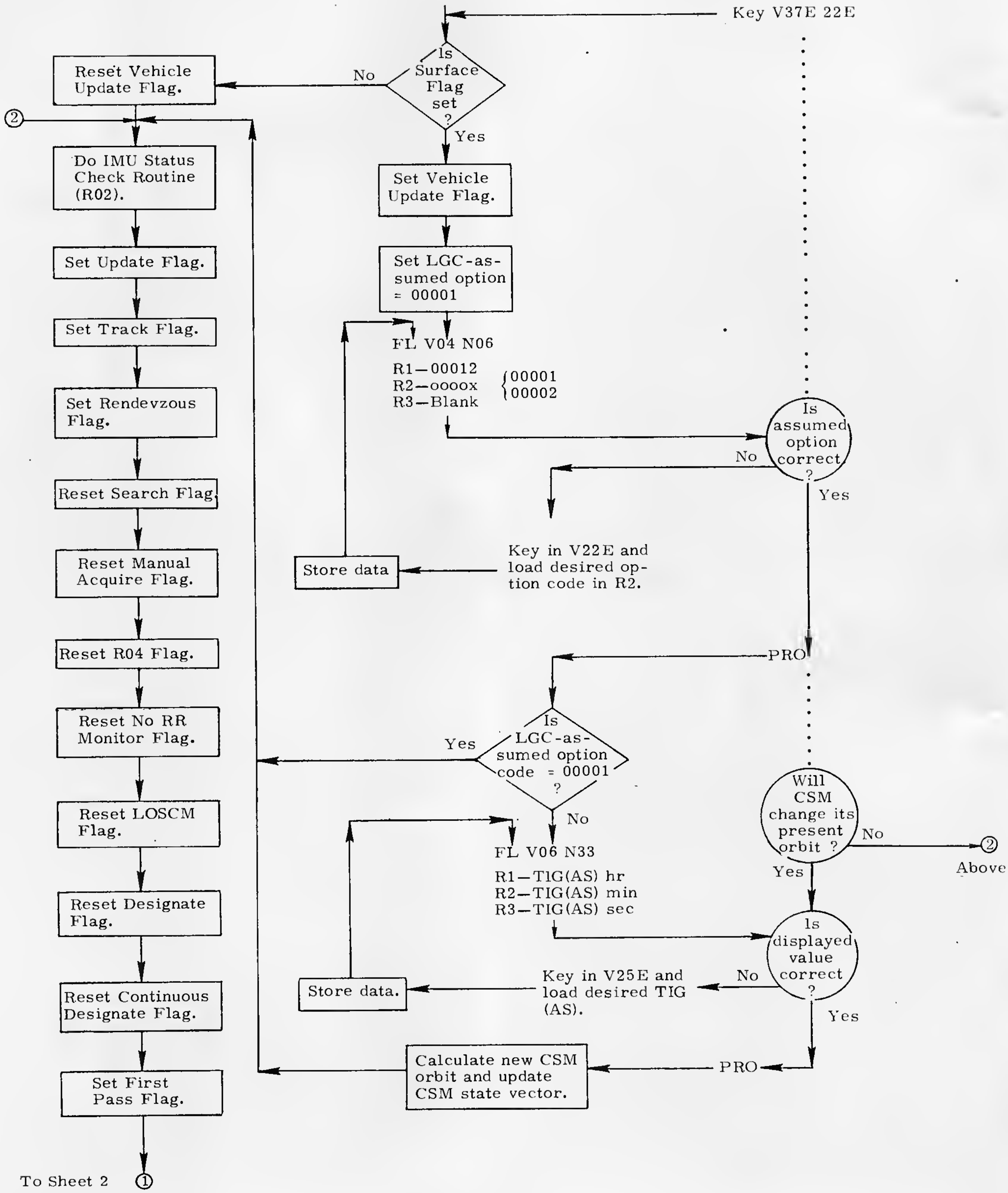


Figure 4.3.3-6. Lunar-surface Navigation Program (LM P22) (Sheet 1 of 5)

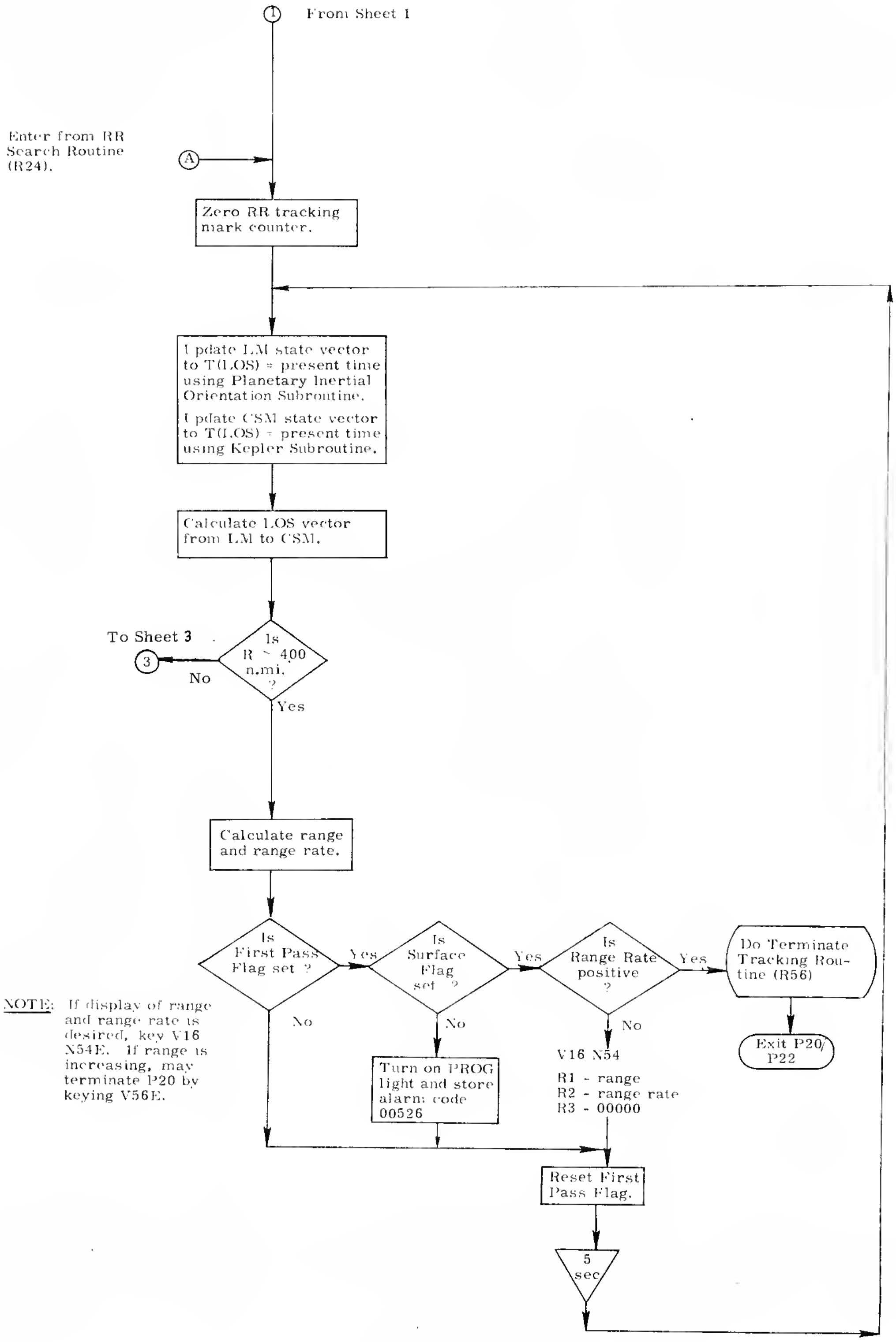


Figure 4.3.3-6. Lunar-surface Navigation Program (LM P22) (Sheet 2 of 5)

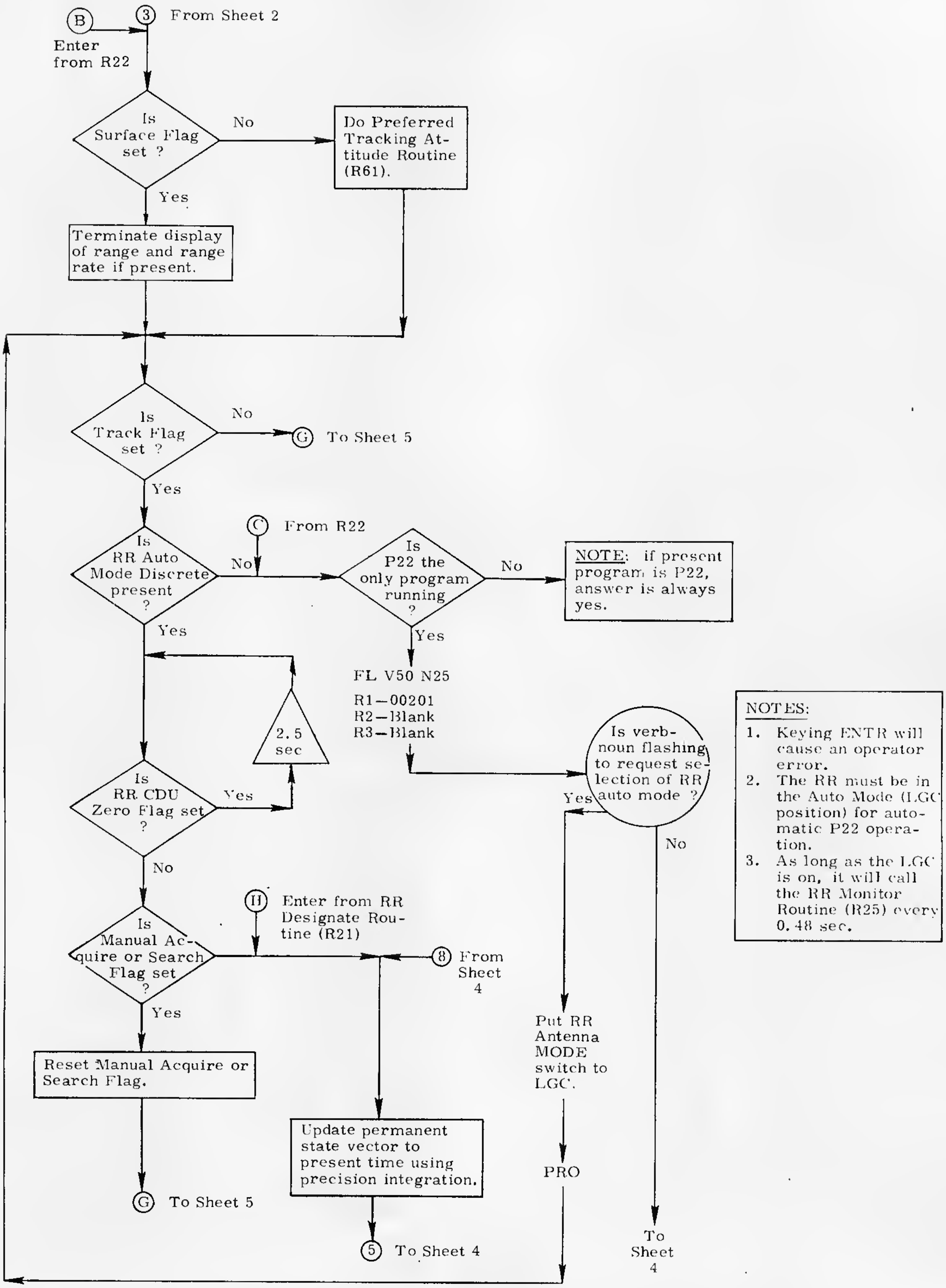


Figure 4.3.3-6. Lunar-surface Navigation Program (LM P22) (Sheet 3 of 5)

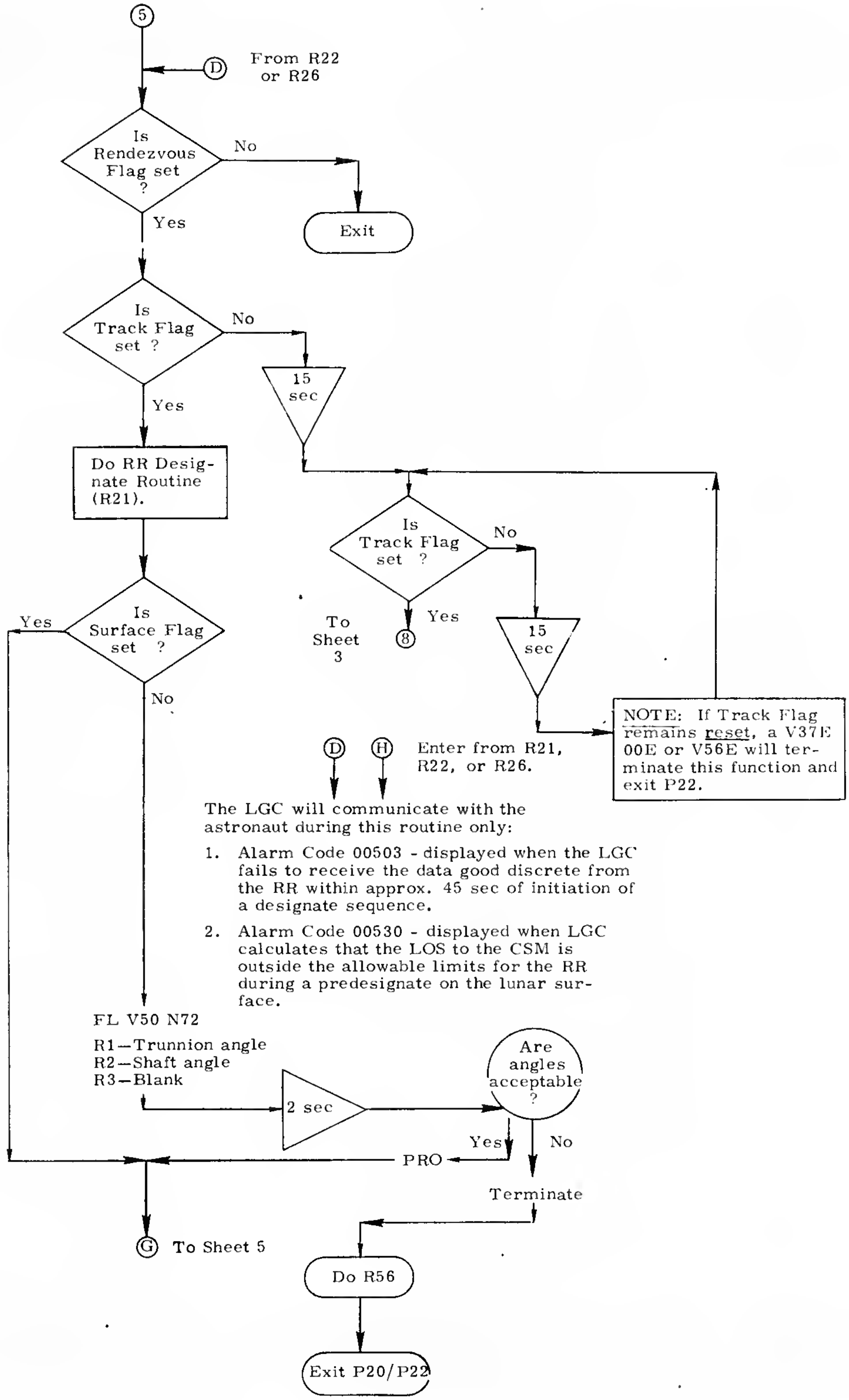


Figure 4.3.3-6. Lunar-surface Navigation Program (LM P22) (Sheet 4 of 5)

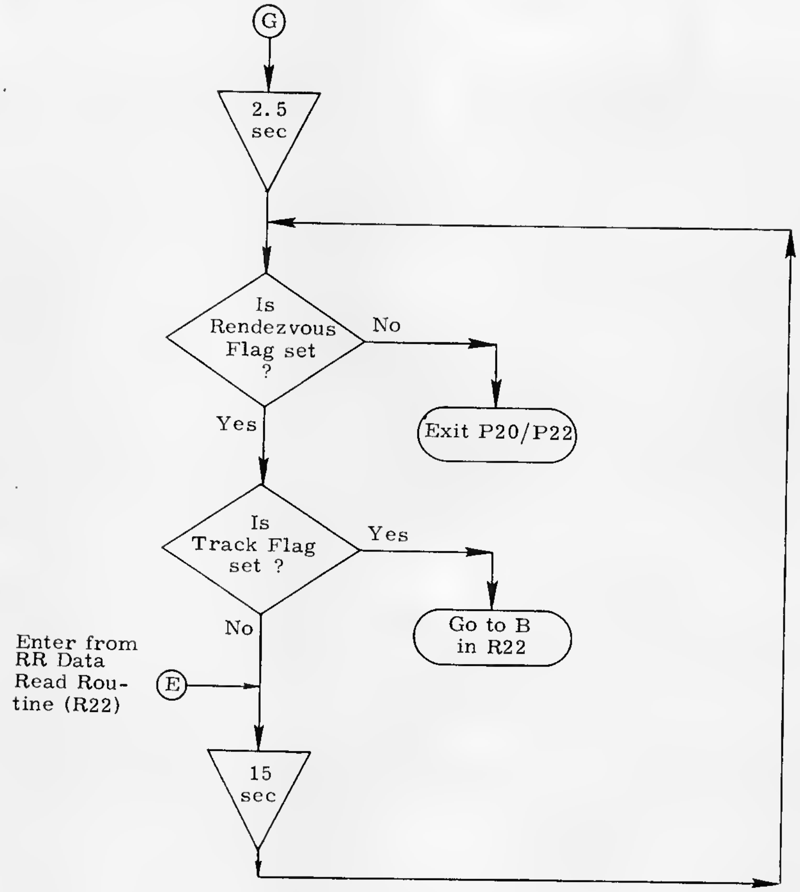


Figure 4.3.3-6. Lunar-surface Navigation Program (LM P22) (Sheet 5 of 5)

TABLE 4.3.3-II

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LUNAR-SURFACE NAVIGATION (LM P22) (SHEET 1 OF 2)

DSKY	By	Purpose	Registers	Remarks
Key V37 E 22E	crew	Enter P22		
FL V04 N06	P22	CSM plane change	R1 00012 R2 0000x	R2=00001 CSM will not change plane. R2=00002 CSM will change plane. PRO if correct, V22E to reload R2.
FL V06 N33	P22	t_{IG} launch GET	R1 xxxxx hrs R2 xxxxx min R3 xxx.xx sec	PRO if correct, V25E to reload t_{IG}
PROG alarm light V05 N09E	R02	IMU status unsatisfactory	R1, R2, R3 xxxxx*	Rx = 00210 means IMU not on; Rx = 00220 means IMU not aligned.
V16 N54	P22	Display of range and range rate.	R1 xxx.xx n. mi. R2 xxxx.x fps R3 00000	R1 = range R2 = range rate Display appears if range is > 400 n. mi. and is decreasing; recalculated every 5 seconds.
FL V50 N25	P22	RR Antenna mode switch not in LGC position	R1 00201 R2 Blank R3 Blank	RR Auto Mode discrete absent. Do not key in ENTR; put RR Antenna Mode switch in LGC position and key PRO.
PROG alarm FL V05 N09	R26	10 minute pre-designate mode entry search limit exceeded.	R1, R2, R3 xxxxx*	Alarm code 00530; ordinarily will not occur since R>400 n. mi. test in P22 ensures less than 8 minutes of pre-designate time.
PROG alarm light FL V05 N09	R21	00503 alarm = RR designate fail	R1, R2, R3 xxxxx	V32E will reinitiate RR Designate (R21). PRO will start R24 the RR Search routine. V34E and V56E will terminate.
PROG alarm light Key V05 N09E	R20	00520 alarm = radar sample, request error or no R04	R1, R2, R3 xxxxx*	Alarm not displayed until astronaut keys V05 N09 to verify PROG. This alarm is likely to occur in combination with others.

* Refer to note in paragraph 3.3.1.6

TABLE 4. 3. 3-II

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LUNAR-SURFACE NAVIGATION (LM P22) (SHEET 2 OF 2)

DSKY	By	Purpose	Registers	Remarks
PROG alarm FL V05 N09	R22	00525 alarm = delta theta (the difference between the RR LOS and the LOS computed from the CSM state vector) is greater than 3°.	R1 xxxxx R2 xxxxx R3 xxxxx	Indicates possible sidelobe lock, keying PRO will display delta theta magnitude; V34E or V56E will terminate P22
FL V06 N05	R22	Size of delta theta will indicate which sidelobe (η[3°] first sidelobe, etc.)	R1 xxx. xx R2 Blank R3 Blank	PRO response will incorporate data despite sidelobe lock V34E and V56E will terminate. V32E will reject mark and take another.
FL V06 N49	R22	ΔR Δv Source code: 1 = range 2 = range rate	R1 xxx. xx n.mi. R2 xxxx. x fps R3 oooox	Marks are incorporated by Keying PRO. Keying V32E will process next measurement. V34E will reject current mark and take another.
FL V16 N80	R24	Permits RR search to be monitored in progress	R1 xxxxx R2 xxx. xx deg R3 Blank	R1: 00000=RR Data Good discrete absent, 11111=RR Data Good discrete present. R2: Omega=Angle between CSM LOS and LM+Z-axis to nearest .01°. Recycle (V32E) will reinitiate search; V34E or V56E will terminate P22; PRO will go to R20 then R22.
PROG alarm Key V05 N09E to verify	R24	Desired target LOS not within RR Mode 2 limits.	R1 xxxxx R2 xxxxx R3 xxxxx	00527 alarm = search pattern outside RR mode limits; may appear in any register with other alarms. V34E or V56E to terminate P22.
PROG alarm Key V05 N09E possible NO TRACK light.	R25	CDU fail	R1 xxxxx R2 xxxxx R3 xxxxx	00515 alarm = CDU failure NO TRACK light indicates data good lost. KEY REL and RSET to reset alarm.

state by the program. The program next performs the IMU Status Check, R02, which can return two alarms (IMU not on, IMU not aligned), both extremely unlikely. After R02, P22 initializes the necessary flags, briefly described in Table 4.3.3-III. The program sets the Update, Track, First Pass and Rendezvous Flags, and resets the Search, Manual Acquire, R04, No RR Monitor, LOCSM, Designate and Continuous Designate Flags. The explanations given in Table 4.3.3-III are largely sufficient. Tracking and marktaking are allowed. The RR is to be operated in the Auto, not in the manual mode. R25 (RR Monitor) is enabled and the LOS to the CSM computation disabled. RR designate (which points the RR is inhibited along with continuous designate (which designates the RR but inhibits RR lock).

The program then zeros the RR tracking mark counter, and extrapolates the LM and CSM state vectors to the present time for the 400-n.mi. check. Appearance of the VERB 16 NOUN 54 display signifies that the range is greater than 400 n. mi. and is decreasing. When range is less than 400 n.mi., P22 checks to see if the RR antenna mode switch is in the LGC position, returning a flashing VERB 50 NOUN 25 and 00201 Checklist code if it is not. Repositioning the antenna mode switch to LGC and keying PRO ensures the presence of the auto mode discrete.

After ensuring that the CDUs are not being zeroed, and that the Manual and Search flags are not set, P22 updates the LM and CSM state vectors to the present time, using precision integration, before entering R21, the Designate Routine.

4.3.3.4.2 RR Designate Routine (R21) and Pre-Designate Routine (R26).—R21 (Figure 4.3.1-8) first removes the RR auto track enable discrete, until designation is accomplished. Next, the routine selects CDU gimbal angles corresponding to the center of the Mode 2 antenna coverage and commands them to the RR, which drives the antenna to the center of Mode 2. R21 then sets the RR designate counter, which allows 60 designate passes (45 seconds) for the RR to obtain lock. The routine then sets the LOSCM flag for use in the designation process. The counter, N, set to 3 in R21, causes the LOS from the LM to the CSM (LOS_{LC}) to be computed every fourth designate pass. The LOS_{LC} is computed 0.5 sec in the future and compared with the Mode 2 limits. Since the program is normally entered 5 minutes before CPA—well before the CSM reaches the RR mode limit—R21 exits at this point to R26, the Pre-Designate Routine, which computes the RR LOS vector at which the CSM will enter the Mode 2 limit.

R26 (Figure 4.3.3-7) computes the optimum orientation for acquisition within Mode 2 and continuously designates the RR to that orientation until the predicted entry time arrives, when it returns control to R21 for the actual designation. R21 then

TABLE 4.3.3-III

FLAGS USED WITH LM P22

Flag Name	Set	Reset
Update	SV updating by RR marks allowed	SV updating by RR marks not allowed
Track	Tracking allowed	Tracking not allowed
Rendezvous	P20 or P22 running	P20 or P22 not running
Search	RR in auto search	RR not in auto search
Manual Acquire	RR manual acquire	RR auto acquire
R04	R04 is running	R04 is not running
No RR Monitor	Bypass RR monitor	Perform RR monitor
LOSCM	LOS being computed	LOS not being computed
Designate	RR designate requested	RR designate not requested or in progress
Continuous Designate	LGC commands RR without lock-on	LGC checks for lock-on
Lock-on	RR lock-on desired	RR lock-on not desired
Range Scale	Scale change during LR/RR	Nc scale change during LR/RR
Surface	LM on moon	LM not on moon
First Pass	First pass	Succeeding pass
First Time	First pass through R26	Succeeding pass

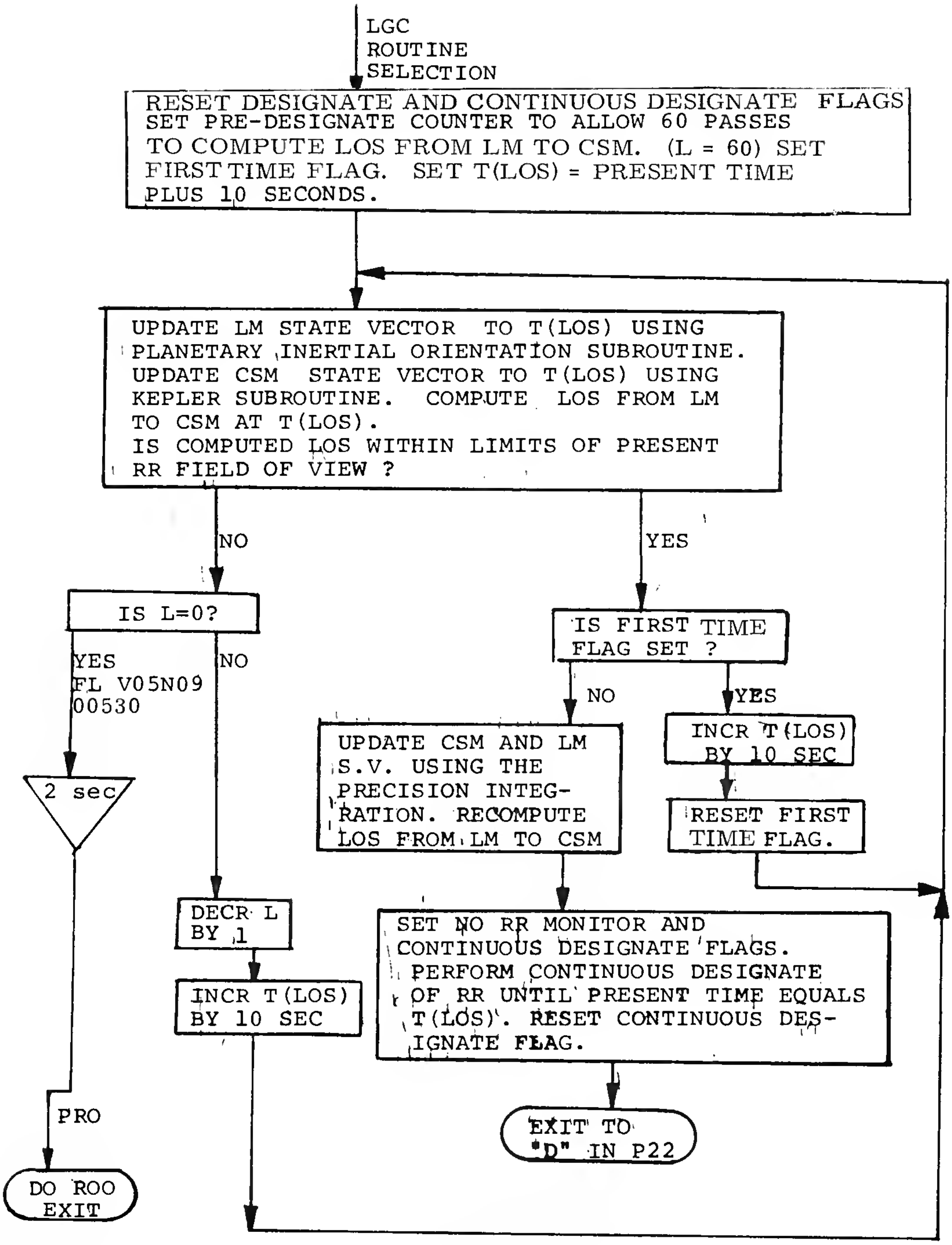


Figure 4.3.3-7. Lunar Surface RR Predesignate Routine (LM R26)

issues rate commands (Figure 4.3.1-8, Sheet 3) proportional to the difference between the present RR LOS and the computed LOS for one second in the future. The LGC continues to designate rate commands until the RR LOS comes within 0.5 deg, at which time the track enable discrete is issued to the RR by the LGC. When the RR achieves radar lock-on, it returns the data good discrete to the LGC. If the RR fails to acquire within 45 seconds (60 passes) the designation process stops and a flashing VERB 05 NOUN 09 PROG alarm light is issued, signifying that the RR is unable to acquire (alarm code 00503). The astronaut normally keys PRO in response, and R24, the RR Search Routine, begins.

When the RR acquires, it issues the data good discrete, which causes control to be returned to P22 from R21, and the Data Read Routine R22, to be entered.

4.3.3.4.3 RR Data Read Routine (R22) and LR/RR Read Routine (R20).—The RR Data Read Routine (Figure 4.3.1-9) processes automatic RR mark data to update the state vector of either the LM or the CSM, as defined by P22. R22 automatically calls R20 (Figure 4.3.1-7) after setting bits 2 and 4 of channel 13. R20 then reads the LR/RR parameter requested by R22, performs various checks to ensure that the system is operating correctly and issues an alarm if errors occur in LR or RR reading.

Several types of exit are possible from R20. Normally, R22 calls R20 once to obtain RR range rate, then reads the 3 ISS CDU angles, the present time, and the 2 RR CDU angles and calls R20 again to obtain RR range. If the data good discrete is present during R20 data read, R22 performs a 3-deg check before incorporating the measurement data. If the data good discrete is lost, R20 causes the TRACKER light to illuminate. When this happens, the program re-enters the Designate Routine automatically and attempts to re-acquire. In the case of CDU failure, R25 lights the TRACKER and PROG lights and stores a 00515 alarm.

When the RR reaches the far mode limit of the marktaking window, the antenna is commanded to the mode reference position and the RR track enable discrete removed by R25, the RR Monitor Routine (Figure 4.3.3-8). The RR immediately loses lock and removes the data good discrete, lighting the NO TRACK light on the RADAR panel. On the next pass, R22 finds track enable missing and return to R21 and from there to R26 where, since the range rate is positive, control is transferred to R00— unless the NOUN 54 display occurred at the start of P22. If so, range and range rate are computed with no display.

In the nominal onboard update case, the CSM state computed onboard is within 3 deg (approximately 3 n. mi.) of the actual RR-CSM track—unless the radar has

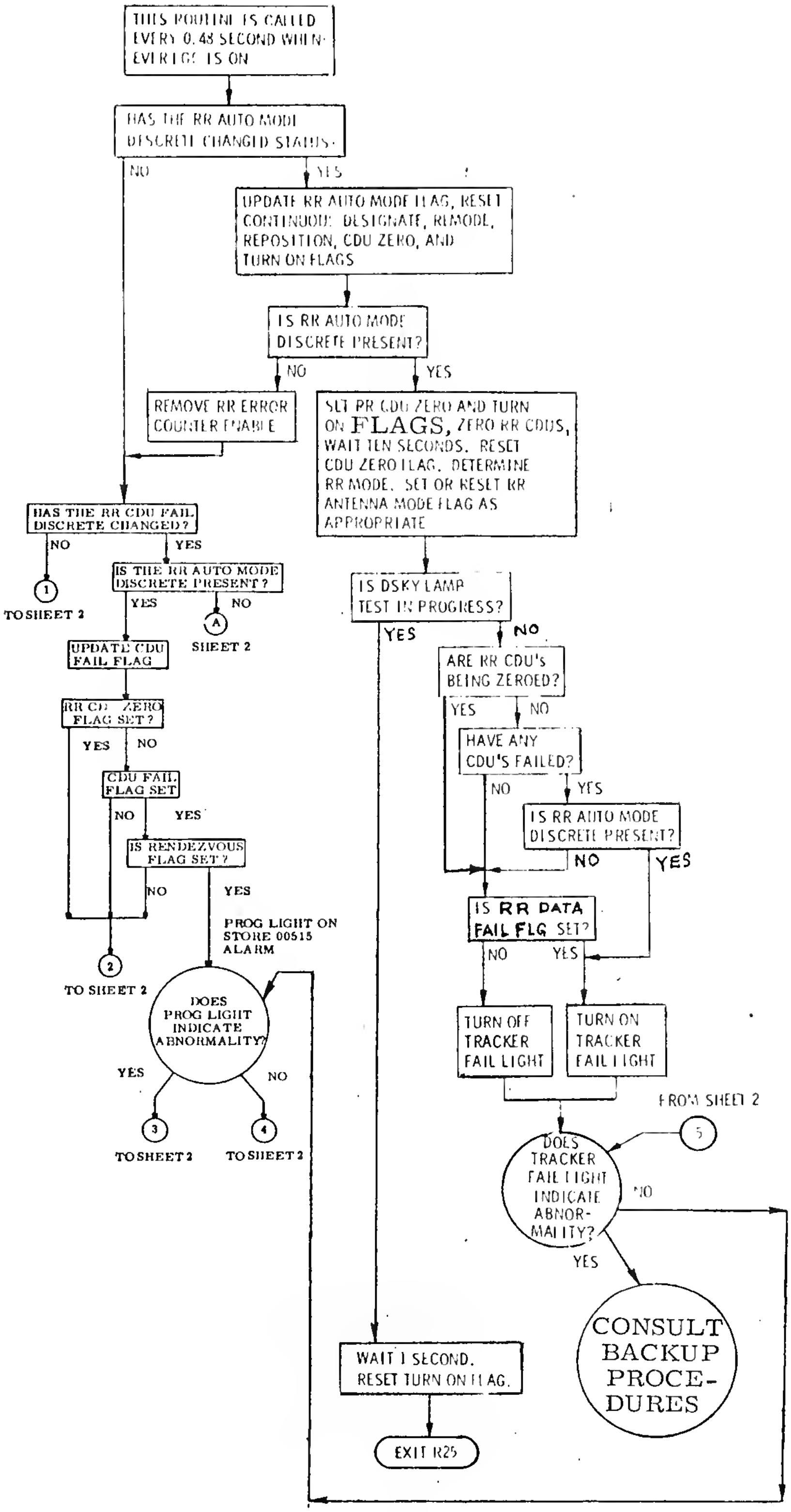


Figure 4.3.3-8. Monitor Routine (LM R25) (Sheet 1 of 2)

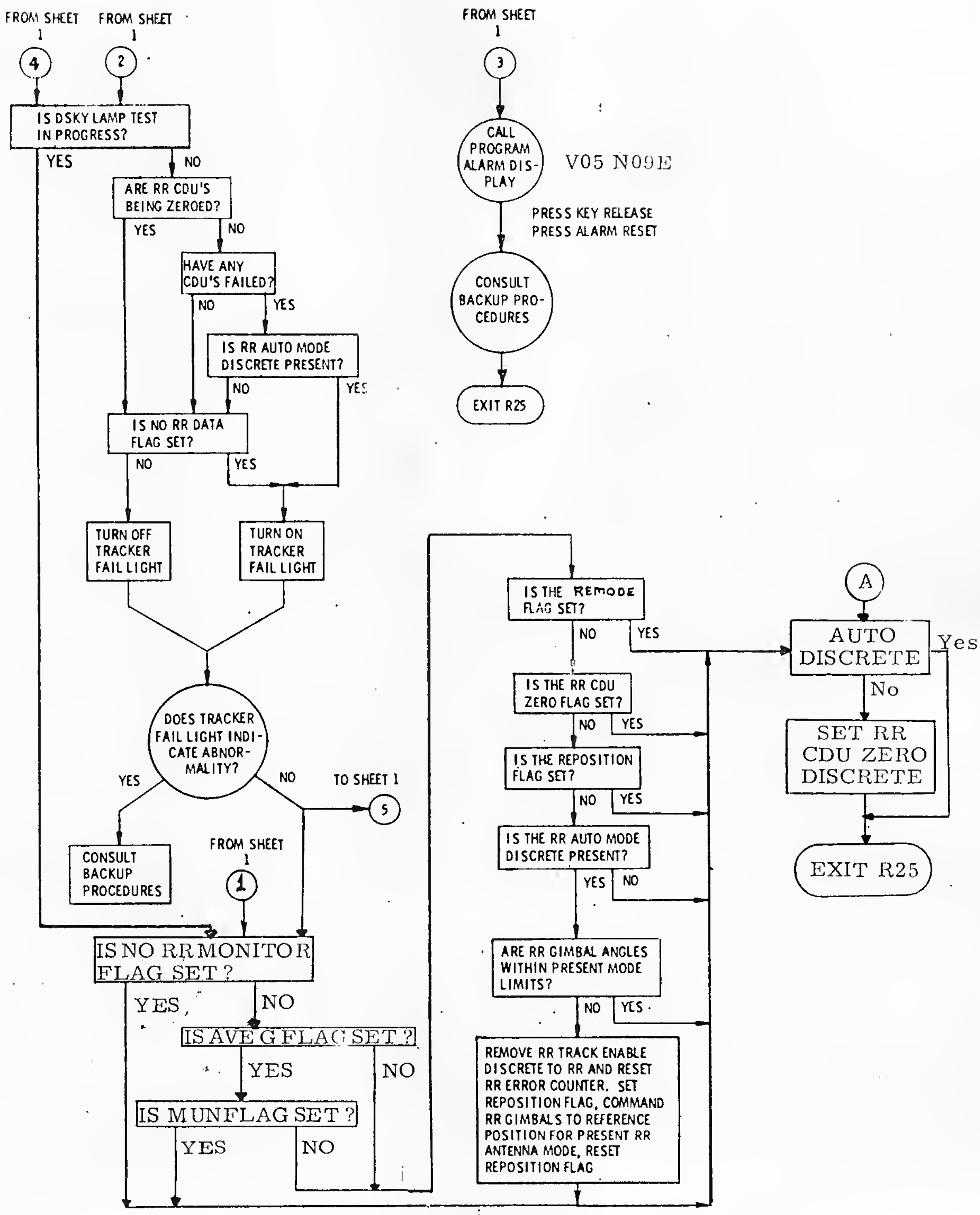


Figure 4.3.3-8. Monitor Routine (LM R25) (Sheet 2 of 2)

achieved lockup on a sidelobe, which is what the 3-deg check is for. In the no update case, the indicated RR CSM LOS may be more than 3 deg from the LGC-computed LOS. The procedure in both cases is to key two PRO responses in succession, each after a 2-sec priority delay. In the nominal case, there is insufficient time to correct a sidelobe lock condition and the range and range-rate data are equally valid—whether acquired via the mainlobe or a sidelobe. In the no update case, the 3-deg check is irrelevant, and the astronaut's only concern is to resume taking RR marks as quickly as possible after the 3-deg check. In the no update case, R22 checks the No Update and Update Flags and returns immediately for the next mark.

In the nominal onboard update case, the program calls INCORP1 to compute the ΔR and Δv resulting from the measurements just read and checks them against a threshold value. If they are below the threshold, they are automatically incorporated and the program returns for the next mark. If ΔR or Δv exceed the threshold, they are displayed via a flashing VERB 06 NOUN 49 display, along with a source code (R3 = 1 or 2 for range and range rate, respectively), for the astronaut's accept or reject decision. Following a PRO response, which causes the mark to be accepted, the program returns for the next RR mark. A VERB 32 ENTR response to the NOUN 49 display causes the last measurement component to be rejected and the next measurement component to be processed. Keying in VERB 34 ENTR rejects all measurement data from this mark. Keying in VERB 56 ENTR terminates R22 and P22.

4.3.3.4.4 RR Search Routine.—If the RR fails to acquire after 45 seconds, the astronaut can initiate the RR Search Routine (Figure 4.3.3-9) by keying a PRO response to the flashing VERB 05 NOUN 09, 00503 PROG alarm. R24 causes the RR to search a 6-sided pattern (Figure 4.3.3-10), which subtends 3.25 deg on each side. Six seconds are spent at the LOS initially designated and six are required to search each side for a total of 42 seconds for the entire search pattern.

4.3.3.5 Summary of Alarms and Displays

The following is a list of the alarms associated with P22, and an explanation of procedures to follow in case of occurrence of these alarms.

a. Alarm code 00210 indicates the IMU is not on. Key KEY REL and RSET and observe flashing VERB 37 requesting entry of new program or routine.

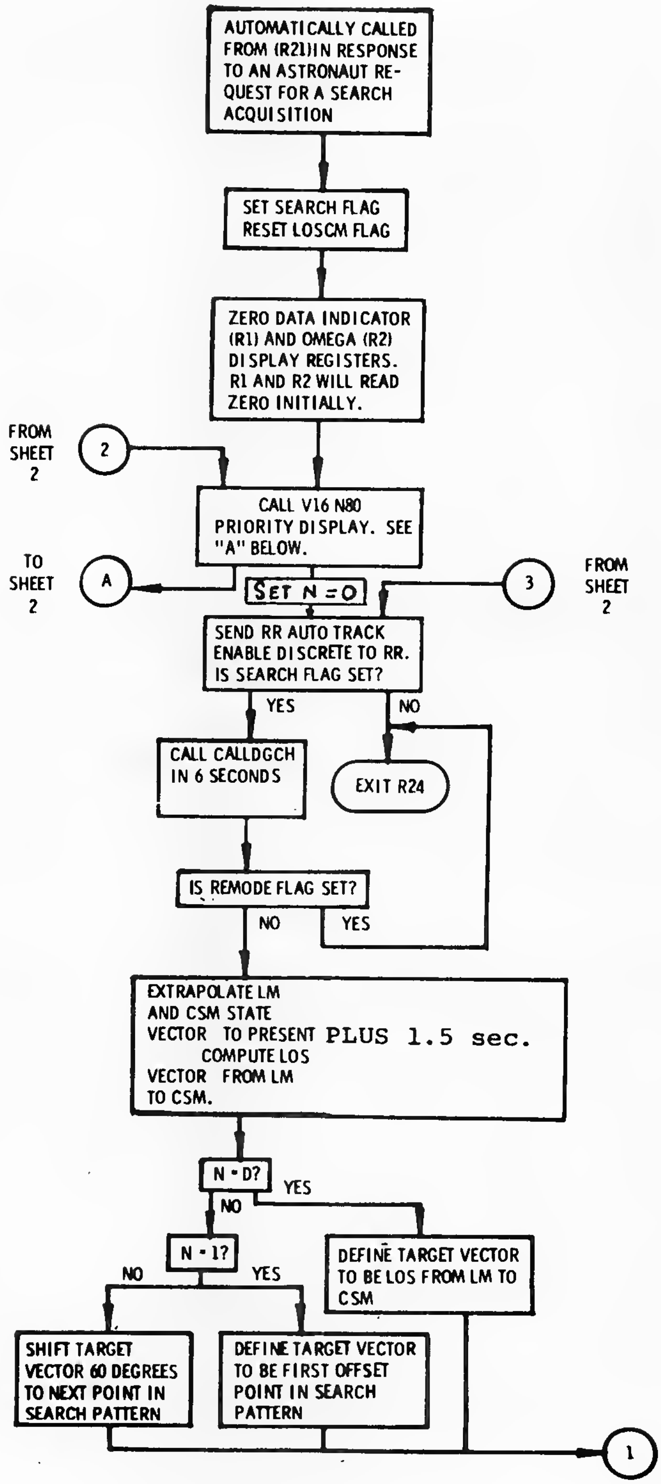


Figure 4.3.3-9. RR Search Mode (LM R24) (Sheet 1 of 2)

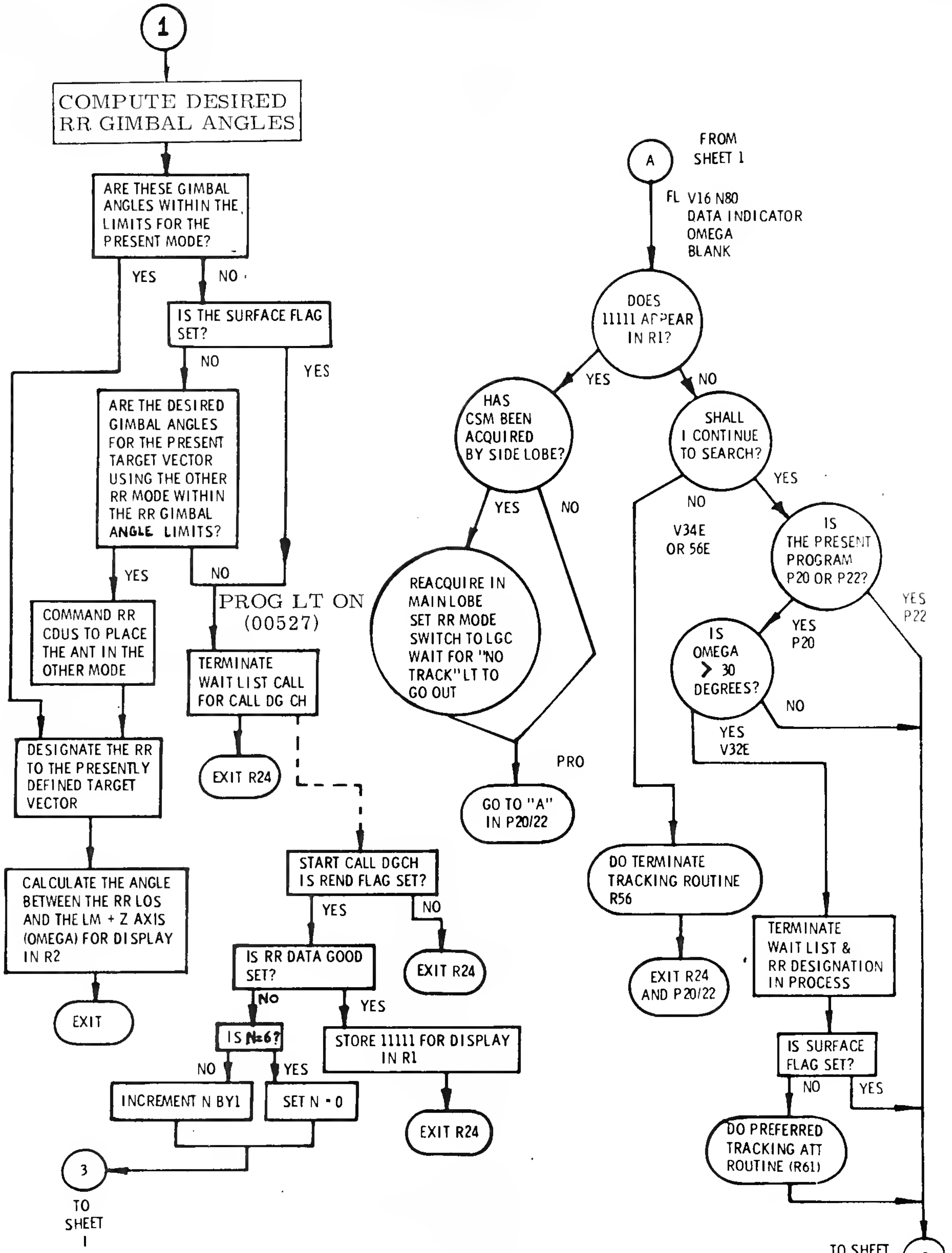
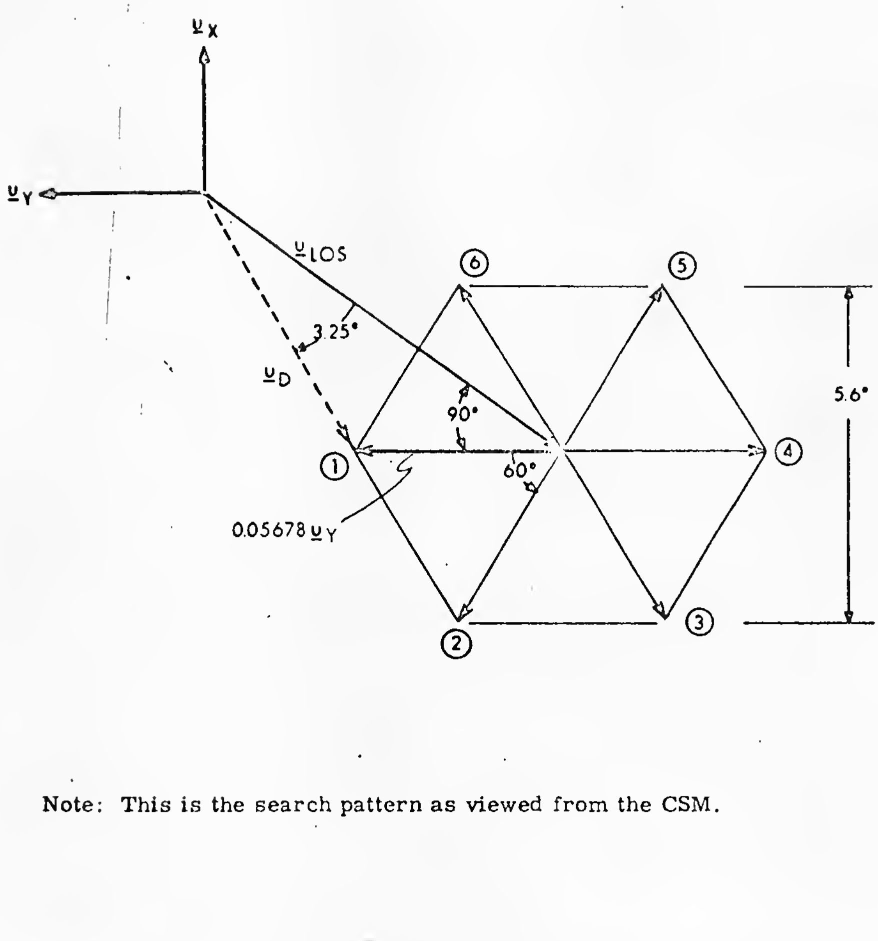


Figure 4.3.3-9. RR Search Mode (LM R24) (Sheet 2 of 2)



Note: This is the search pattern as viewed from the CSM.

Figure 4. 3. 3-10. RR Search Pattern

b. Alarm code 00220 indicates the ISS orientation is not known. Key KEY REL and RSET. Observe flashing VERB 37 requesting new program entry. Perform Lunar Surface Alignment Program (P57).

c. Alarm code 00530 indicates the LOS is not in Mode 2 coverage on the lunar surface after 10 minutes. Perform time check for P22 recall. Key PRO. Exit R26, R21 and P22.

d. Alarm code 00503 indicates the RR is unable to acquire thc CSM. Key RSET. To redesignate the RR, key V32 ENTR. To initiate the RR Search Routine, R24, key PRO.

e. Alarm codc 00527 indicates the CSM is out of RR Mode 2 limits. Exit P22.

f. Alarm code 00520 indicates either that RADARUPT (LGC interrupt) is not expected at this time, or that no radar sampling has been requested at this time. Key KEY REL and RSET and return to R21 for automatic reacquisition.

g. Alarm code 00525 indicates that $\Delta\theta$ is greater than 3 deg. To terminate P22, key RSET and VERB 34 ENTR or VERB 56 ENTR. To continue, key RSET and PRO.

h. Alarm code 00515 indicates an RR CDU failure. Key KEY REL and RSET and attempt to continue P22 using any additional alarm code, and MSFN to evaluate CDU performance. If CDU performance remains unsatisfactory, terminate by keying VERB 56 ENTR.

Table 4.3.3-II lists the regular verbs and DSKY displays in the order in which they occur in P22. Familiarity with the details of the individual routines, the acquisition sequence and the data incorporation process is assumed from the foregoing discussion. In the discussion that follows, emphasis is in proportion to operational significance. Several displays are straightforward enough and the response to them sufficiently predictable that they are virtually automatic (e.g., the flashing VERB 50 NOUN 25 with 00201 alarm that signifies that the RR auto mode discrete is absent). Several others, particularly some of the alarms caused by off-nominal conditions, are highly unlikely (e.g., the 00210 and 00220 unsatisfactory IMU status and 00515 CDU failure alarms). Ultimately, four key displays provide the basis for all the critical decisions the astronaut can make in P22. The astronaut's response to the first display in P22, the plane-change option, is predetermined by the flight plan and, therefore, requires a minimum of thought on his part and little discussion. He will PRO on the 00001 in R2 in most instances since the CSM orbit does not precess appreciably for near-equatorial orbits and, even if communications have failed, an MSFN-computed state vector will have been uplinked, on the previous orbit, that will include the necessary plane change.

The two IMU PROG alarms (00210 IMU not on; 00220 IMU not aligned) can occur only as the result of some gross failure. At 60 n. mi., the CSM comes within the RR 400-n. mi. range limit 466 seconds (~7 min, 45 sec) before CPA and 335 seconds (5 min, 35 sec) before the nominal Mode 2 limit (where nominal applies only when the LM is level). The astronaut can monitor range and range rate via the VERB 16 NOUN 54 display until range is less than 400 n. mi. By monitoring range in R1 and knowing that the Mode 2 limit will be entered at about 120 n. mi., he can anticipate the time at which designation will begin within a few seconds.

The flashing VERB 50 NOUN 25 with 00201 code is simply a reminder to place the RR antenna mode switch in the LGC position, and has no special operational significance otherwise.

The RR CDU fail alarm is unlikely to occur; the procedure for verifying and correcting it is to zero the CDUs (via V40N72 or by cycling the RR mode switch from LGC to SLEW and back), wait 10 seconds, then clear the alarm. If alarm persists, RR CDU has failed; exit program and consult contingency procedures. (Refer to Table 4.3.3-IV.) The 00527 alarm will occur when the CSM exits Mode 2.

The 00503 designate fail alarm is a crucial decision point during P22 acquisition. The astronaut will monitor the RR displays closely as the CSM enters the mode limit and will be able to tell from the SIGNAL STRENGTH meter if an RF return from the CSM transponder has been received, possibly one too weak or intermittent to permit lock. The Designate Routine will designate the radar for 45 seconds before returning the 00503 alarm, and, since acquisition would presumably have taken place if the computed CSM position were not in error, an immediate PRO response to initiate an RR search is indicated. The data good discrete will cause the TRACKER light to go out when RR data are received, if it had been previously lit.

> NOTE:—P22 does not update the TRACKER light before the data good discrete is received, so that its condition is not a reliable guide prior to RR lock-on. The NO TRACK light (on the RADAR panel) is wired directly to the RR tracking loop and is the best lock indicator.

If the flashing VERB 05 NOUN 09 display and 00525 PROG alarm occur in P22 (indicating actual RR LOS greater than 3 deg from computed CSM LOS), the correct response is to PRO, wait 2 seconds to see if the flashing VERB 06 NOUN 05 Delta Theta display confirms sidelobe lock, and to quickly PRO again, incorporating the data regardless of sidelobe lock.

TABLE 4.3.3-IV
P22 (LM) VERBS AND EXTENDED VERBS

DSKY	Identification	Purpose	Remarks
V41 N72E	RR CDU	To drive RR shaft and trunnion to angles specified (via V21 N73) by astronaut, and either (via V04 N12) continuously designate along that vector or permit RR lock.	Cannot be used during P22. Can be used prior to entering P22 to pre-position RR antenna to shaft and trunnion angles of desired LOS. PROG alarm (code 00502) if desired LOS is outside mode limits; 00503 if Designate Fail (with 00515 if CDU Fail). Continuous Designate terminated only by V44E.
V06 N72 E or V16 N72 E	Display RR shaft and trunnion angles.	To monitor current RR shaft and trunnion angles.	Can be used during P22 and with other extended verbs.
V 44E	Terminate V41 N72	Terminates continuous designate option in V41 N72 (above)	
V 56E	Calls R56	Terminates P22	Selects R00 (same as V34E) except V56 need not be selected at flashing displays
V 67E	Displays W-matrix	Displays W-matrix RSS error.	
V83E	Calls R31	Computes and displays rendezvous parameters R, $\dot{R}$, θ. θ is angle between LM Z-axis and horizontal.	R display useful to judge designate initiation. IMU must be on for correct θ values. θ used to alter Mode 2 acquisition limit if LM is not level.
V85E	Displays RR Az and El	Displays RR antenna azimuth and elevation in R1, R2.	Cannot be used with any other extended verb active.
V95E	Sets no update flag	Inhibits CSM state vector update	Used when data are downlinked for ground computation.
V 06 N38E	Displays TET	Displays progress of state vector integration. Time (TET) to which state vector is presently integrated R1 hrs R2 min R3 sec	TET to nearest 0.01 sec.

4.3.3.6. Restrictions and Limitations

The ISS must be on and the IMU on and aligned accurately to a known inertial attitude, via P57, for the LGC to compute RR pointing information necessary for automatic acquisition of the CSM.

The RR Self-Test Routine must have been performed prior to entering P22.

The RR can track only within the Mode 2 limits (Figures 4.3.3-2 and 4.3.3-3) in P22.

P22 is to be operated in the no-update mode only. A zero W-matrix is stored for use with P22, and, therefore, assures no-update performance (ΔR equals 0; Δv equals 0).

4.3.3.7 Restarts

Restarts cause the program to return to a previous display unless they occur after the Data Read Routine is processing a mark. In the update mode, if a restart occurs while a set of mark data is being processed for incorporation, the program returns and processes the next available set of mark data, and the original RR mark will be lost along with the processing time. If the restart occurs after the mark data have been processed into an update, but before they have been accepted and/or read into the state vector, the program returns for the previous mark data and only the initial read-in time is lost.

In the no-update mode, marks are taken approximately every 3.5 seconds and a restart may cause the loss of one mark.

4.3.4 P25, Preferred Tracking Attitude—LGC

The Preferred Tracking Attitude Program, P25, is a backup program to the Rendezvous Navigation Program, P20. P25 is selected when Rendezvous Navigation fails to operate correctly. P20 failure can be recognized during the Rendezvous Radar Self-Test Routine (R04), or through the behavior of P20, itself. Recurring NOUN 49s with Δr or Δv of large magnitudes, or a diverging trend in the VERB 06 NOUN 05 $\Delta\theta$s would notify the crew of P20 malfunctions. Should the rendezvous radar malfunction and prevent the correct operation of P20, P25 would be selected by the crew to provide a LM-preferred tracking attitude enabling CSM tracking of the LM optical beacon. P25 computes the preferred tracking attitude and performs the maneuver of the LM to this attitude for rendezvous. The preferred tracking attitude specified by P25 is obtained when the LM +Z-axis is aligned along the LOS to the CSM, and the roll attitude (about the LM +Z-axis) is unconstrained and is defined as necessary to avoid gimbal lock. The LM tracking beacon field of view is a 30-deg half-angle cone with the cone axis parallel to the LM +Z-axis. P25 will continue to maintain the preferred tracking attitude until its termination via the Terminate Tracking Routine (R56).

4.3.4.1 Procedures

Figure 4.3.4-1 diagrams the functional flow of P25; Table 4.3.4-I is a summary of P25 displays.

P52 or P57 must be completed before the selection of P25. As mentioned above, P25 is selected when P20 fails to operate correctly. Entry is made by keying VERB 37 ENTR 25 ENTR into the DSKY, and observing P25 on the DSKY major mode indicator. If the Attitude Control switch is not already in the LGC Auto Mode position, the astronaut puts it in this position. P25 then calls the IMU Status Check Routine (R02) to ensure that the IMU is aligned to an orientation known by the LGC. If the IMU is off, or its orientation is unknown, the PROG alarm light is illuminated. The astronaut then keys VERB 05 NOUN 09 ENTR to identify the abnormality. Alarm code 00210 is displayed if the IMU is not on; 00220 is displayed if the orientation is unknown. The astronaut keys KEY REL and RSET and resets the alarm. A flashing VERB 37 indicates the program has entered the Final Automatic Request Terminate Routine (R00). If the IMU is on and the orientation is known, the IMUSE flag is set indicating the IMU is in use, and R02 is terminated.

P25 then automatically sets the Track flag indicating that tracking is allowed. R65 checks to ensure that the GUID CONT switch has been set to PGNS and that the PGNS MODE CONTROL switch has been set to AUTO. If it is not in this position,

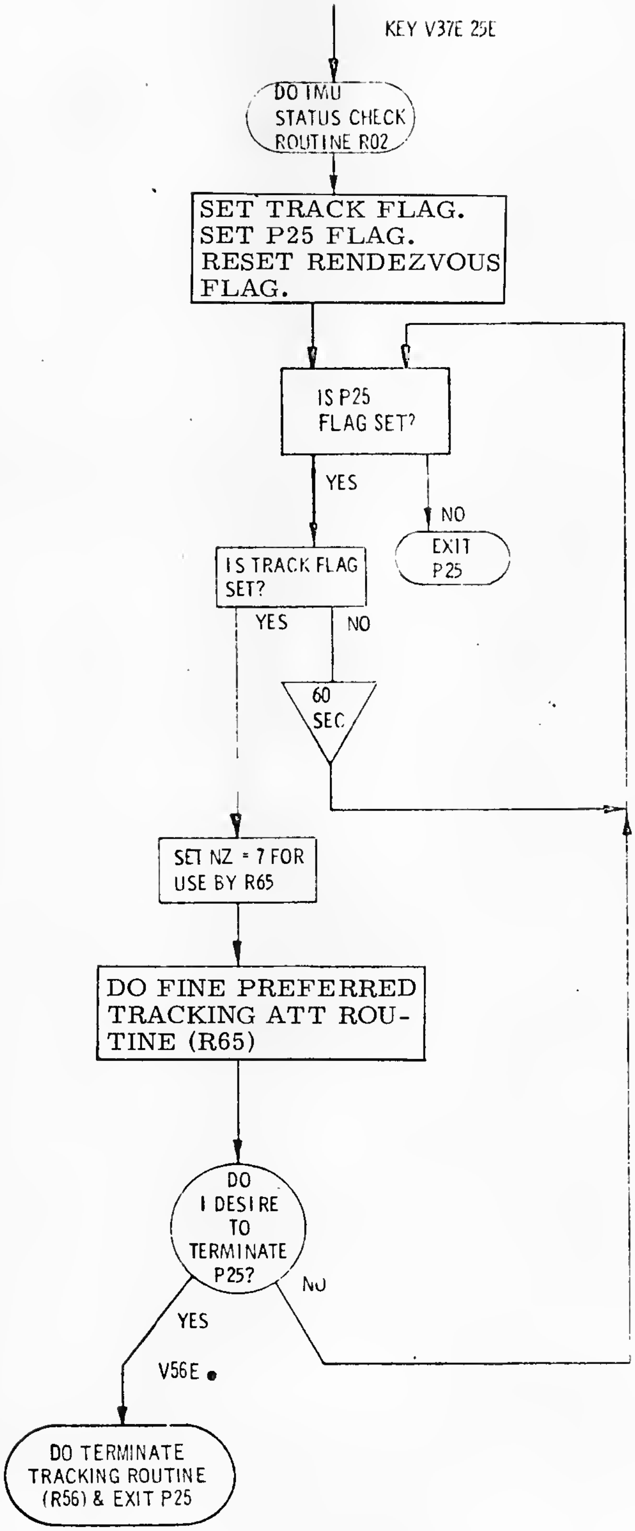


Figure 4.3.4-1. Preferred Tracking Attitude (LM P25)

TABLE 4.3.4-I

DISPLAYS ASSOCIATED WITH

THE PREFERRED TRACKING ATTITUDE PROGRAM

(LM P25)

DSKY	Initiated By	Purpose	Register
FL V50 N18*	R60	R1 = roll R2 = pitch R3 = yaw Requests astronaut to perform automatic maneuver via R60 to attitude specified by P25. Displays final FDAI angles for the maneuver.	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg

*Priority display if R60 is called by R65.

the program will recycle until it is. The crew has no indication of this recycling process. The P25 flag is automatically set indicating that P25 is running. These flags are then checked by the LGC to ensure they are set and have not been reset by some other LGC program.

N_Z, a counter index, is automatically set to 7 before calling the Fine Preferred Tracking Attitude Routine (R65), so that R65 will perform the Z-axis alignment eight times at 6-sec intervals. P25 then calls R65, which obtains continuous fine Z-axis tracking. R65 performs a series of automatic trim maneuvers to the preferred tracking attitude, unless a required maneuver exceeds 15 deg. If so, the crew is notified via a flashing VERB 50 NOUN 18 that a vehicle maneuver is required via R60.

When N_Z equals 0 in R65, the routine is exited, P25 then checks the Track flag. If the Track flag is not set, P25 will wait until the Track flag is restored. This can only be done by program control and is not a crew function.* When he no longer needs to maintain the preferred tracking attitude (i.e., when rendezvous is complete), the crew member can terminate P25 by keying in VERB 56 ENTR, initiating the Terminate Tracking Routine (R56).

4.3.4.2 Computational Sequence

Below is a discussion of the routines called by P25, in the order in which they are called, with a brief discussion of the function of each routine. Some of this material may overlap the discussion given above, but will provide an event-flow description that is logically consistent with Figure 4.3.4-1.

First, the IMU Status Check Routine, R02, (Figure 4.3.4-2) is called by P25 to ensure that the IMU is on and is aligned to an orientation known by the LGC. If it is not on, program alarm 00210 occurs. If the orientation is unknown by the LGC, program alarm 00220 occurs. The astronaut then keys VERB 05 NOUN 09 to identify the abnormality.

Next, the Fine Preferred Tracking Attitude Routine, R65, (Figure 4.3.4-3) is called by P25 to perform a series of trim maneuvers to the preferred tracking attitude, if each maneuver is less than 15 deg. R65 checks to ensure that the GUID CONT switch has been set to PGNS and that the PGNS MODE CONTROL switch has been

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* The Track flag is reset by VERB 37 selection of any program, and is set by programs P30, P32, P33, P34, P35, P72, P73, P74, P75, P76 and P77.

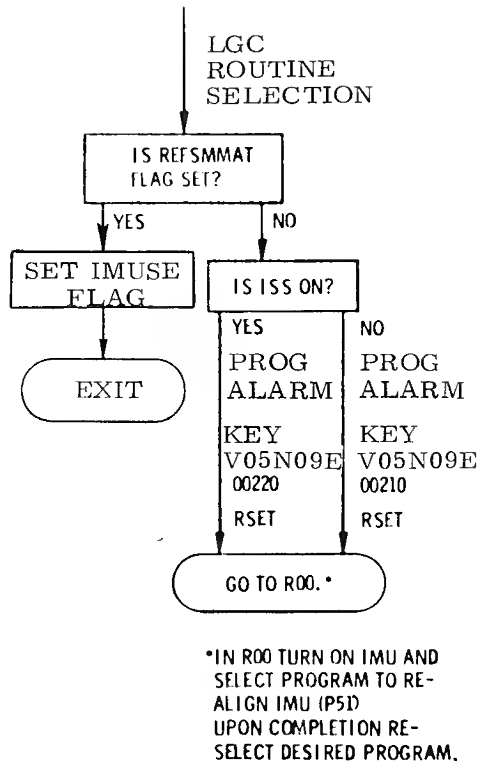

Figure 4.3.4-2 IMU Status Check Routine (LM R02)

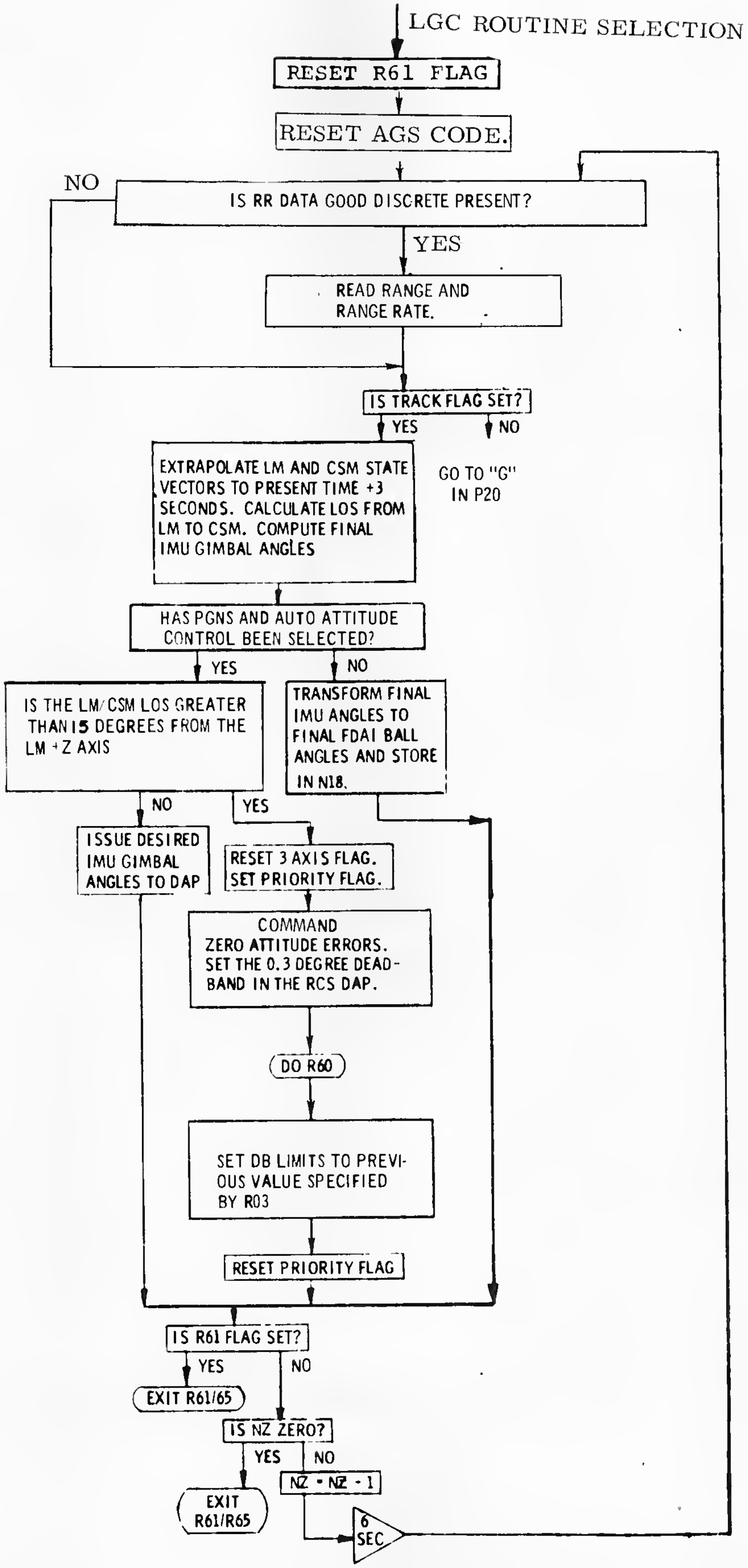

Figure 4.3.4-3 Fine Preferred Tracking Attitude Routine (LM R65)

set to AUTO. If a required maneuver exceeds 15 deg, the crew is notified that an attitude maneuver is required via the Attitude Maneuver Routine (R60). R65 computes the preferred tracking attitude of the LM, enabling CSM tracking of the LM beacon. P25 calls for this program to perform the fine Z-axis alignment eight times.

The Attitude Maneuver Routine, R60, (Figure 4.3.1-14) is called automatically by R65 if the maneuver required to perform the preferred tracking attitude exceeds 15 deg. R60 maneuvers the LM to an attitude specified by P25. A priority display requiring a minimum of 2-sec wait before any keyboard activity acknowledgement (flashing VERB 50 NOUN 18) requests the astronaut to perform the maneuver automatically via R60. The registers R1, R2, R3 display the FDAI angles (roll, pitch, and yaw, respectively).

When the LM has achieved the preferred tracking routine and rendezvous has been completed, the Terminate Tracking Routine, R56, (Figure 4.3.4-4) is called by the astronaut's keying in VERB 56 ENTR. R56 automatically terminates P25 if it is running in conjunction with another program; otherwise, R56 selects R00 to exit P25.

4.3.4.3 Program Alarms

Only two alarms are associated with P25. They are alarm codes 00210 and 00220, which can occur during the IMU Status Check Routine (R02). Code 00210 indicates the IMU is not on; code 00220 indicates the IMU is aligned to an orientation unknown by the LGC. If the PROG light is illuminated during the computational sequence of P25, the astronaut keys VERB 05 NOUN 09 ENTR to identify which of the two alarms has occurred. He then keys KEY REL and RSET on the DSKY to reset the alarms. A flashing VERB 37 indicates that, as a result of the alarm, P25 has entered the Final Automatic Request Terminate Routine (R00).

4.3.4.4 Restrictions and Limitations

P25 is called in the event of a rendezvous radar malfunction, so any degradation of the system would, of necessity, relate to that malfunction. Range and range-rate, angle error detection, shaft and trunnion-angle error-angle measurements would be impaired. P25 will, however, continue to maintain the preferred tracking attitude enabling CSM tracking of the LM optical beacon until it is terminated by the crew.

4.3.4.5 Restarts

P25 is restart protected against hardware and software restarts.

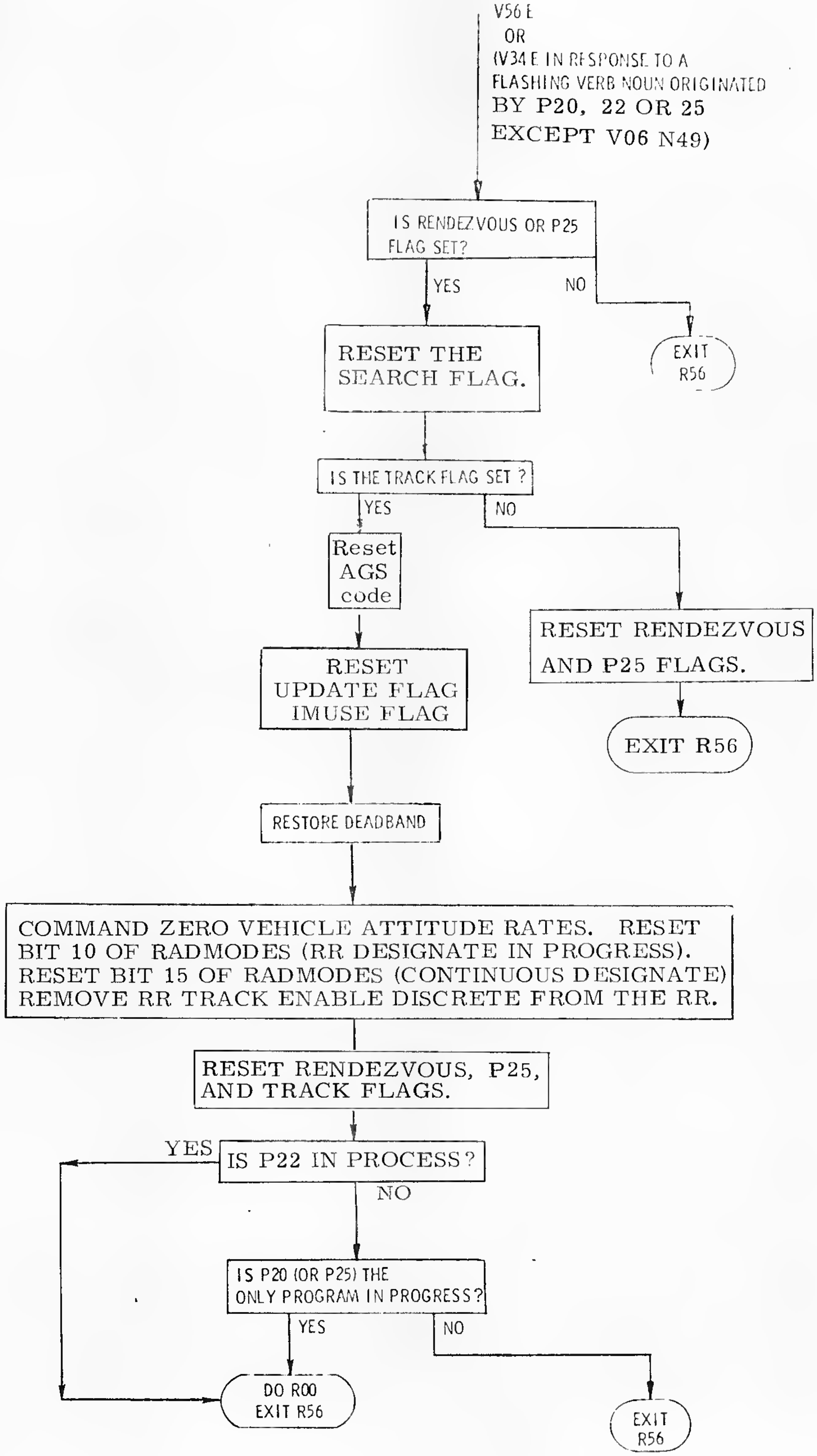

Figure 4.3.4-4 Terminate Tracking Routine (LM R56)

4.3.5 P27, LGC Update

The LGC Update Program is sufficiently like the CMC Update Program that a repetition of description and procedure would be superfluous. Refer to paragraph 4.2.5 for a complete description of CMC update. To adapt this to be applicable to the LM, the reader should note the following:

a. Change each reference to the CSM to LM, and each reference to the CMC to LGC.
b. Rather than the UP TLM switch, the LM has an UP DATA LINK switch which should be in DATA to accept uplinked data.
c. The LGC must be in P00 for P27 to be allowed to interrupt.
d. VERB 71 can be used for any update, but is usually used to perform an LGC CSM/LM state-vector update, an LGC desired REFSMMAT update, or an LGC REFSMMAT update.*
e. The Universal Tracking options (P20 CMC) do not apply to the LGC.

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*Note that the REFSMMAT address for the LGC is different from that of the CMC.

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SECTION 5.0

TARGETING

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5.1 INTRODUCTION TO AGC TARGETING

The onboard targeting routines are used before every mission maneuver requiring a P40, P41, or P42 thrusting program. The following is a partial list of maneuvers and their associated targeting programs:

Maneuvers Targeted by P30

- Lunar-orbit Insertion (LOI_1) and Circularization (LOI_2)
- Transearth Insertion (TEI)
- Descent-orbit Initiation (DOI)
- Translunar and Transearth Midcourse Corrections (MCC)
- Translunar and Transearth Way-Station Return-to-Earth Aborts (RTE)
- Phasing Maneuvers
  (rendezvous maneuvers that onboard
  rendezvous programs cannot target)
- Some Rendezvous Out-of-plane Maneuvers

Maneuvers Targeted by P31-P36 (the Rendezvous Sequence)

- P31 Height Adjustment Maneuver (HAM)*
- P32 Coelliptic Sequence Initiation (CSI)
- P36 Plane Change (PC)*
- P33 Constant Delta Height (CDH)
- P34 Transfer Phase Initiation (TPI)
- P35 Transfer Phase Midcourse (TPM)

Maneuvers Targeted by P37

- Return to Earth (RTE)

Although there is no computer requirement (i.e., there is no alarm indicating an obsolete state vector) for navigation during any part of the mission, the targeting programs are normally preceded by navigation or state-vector uplink to improve the onboard estimate of the current vehicle state vectors. The computer targeting will miss the desired objectives to the degree that position and velocity estimates in the APOLLO guidance computer (AGC) are inaccurate. Further, state vector

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*CMC only.

estimates degrade with the passing of time; it follows that the closer good navigation or state vector uplink is performed to the selection of a targeting program, the better will be the targeting—hence, the better the maneuver.

Every CM P40 or P41 maneuver or LM P40, P41, or P42 maneuver must be preceded by one of the P3x targeting programs. The targeting programs calculate the burn parameters necessary for a thrusting maneuver.

There are, in fact, five classes of maneuvers, four of which involve targeting:

1. Pretargeted maneuvers comprise earth-orbit insertion, translunar insertion, lunar landing, aborts and lunar ascent, and reentry. (Strictly speaking, LM P70 and P71 aborts are not pretargeted, but the distinction between them and the other maneuvers mentioned in class 1 will not be evident to the crew.)
2. Ground-targeted maneuvers comprise LOI, TEI, DOI, various orbital changes around the moon, and translunar and transearth midcourse corrections, or return to earth aborts.
3. Rendezvous maneuvers comprise HAM,* CSI, CDH, TPI, TPM, and PC.*
4. Return-to-earth maneuvers comprise cislunar aborts without communication.
5. Untargeted maneuvers comprise docking, passive thermal control, crew-originated attitude maneuvers (R62), etc.

Clearly, the AGC targeting programs involve only classes 2, 3, and 4. P30 relates to all class 2 maneuvers and some out-of-plane maneuvers. P31–P36* target most rendezvous (class 3) maneuvers. P37 targets all class 4 maneuvers. The remainder of this introduction examines considerations relative to classes 2–4 and, then, summarizes the methods of targeting computation and the coordinate system (local vertical) used in targeting.

5.1.1 Class 2 Maneuvers (P30)

All maneuvers in class 2, ground-targeted maneuvers, are uplinked to the AGC into P30 registers. For these maneuvers, P30 is not precisely a targeting program, but a program for checking data transmitted from the ground and the compatibility of onboard and ground state vectors. In addition to uplinked maneuvers, however,

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*P31 and P36 apply to CMC only.

P30 can be used to target rendezvous out-of-plane maneuvers. Such maneuvers take advantage of P30's convenience as a method for targeting maneuvers conceived in local-vertical coordinates. (Local-vertical coordinates, which are relevant to all targeting programs, are discussed in paragraph 5.1.5.)

Primarily, then, P30 is a program for displaying various burn-related parameters for astronaut approval and for calculating the matrix that relates local-vertical coordinates to basic-reference coordinates used by the thrusting programs.

5.1.2 Class 3 Maneuvers (Rendezvous)

In contrast to P30, which is a general-purpose targeting program, each of the other targeting programs has a specific purpose. The rendezvous-targeting programs are P31–P36.* The following is an overview of rendezvous considerations that should prove helpful when examining the individual programs. (Rendezvous navigation is discussed in paragraph 4.2.1.)

Basically, there are two methods for achieving rendezvous: (1) direct transfer to intercept; (2) rendezvous using intermediate parking orbits. The AGC has the means for targeting both types of rendezvous. Each method has advantages and disadvantages. The direct transfer is faster, but certain abort situations pose problems: (1) lighting conditions cannot be standardized, (2) there are often large maneuver magnitudes, (3) closing rates may be quite fast, and (4) the final approach cannot be standardized to simplify training and monitoring requirements. Parking-orbit rendezvous, on the other hand, allows the final phase to be standardized and permits smaller maneuver magnitudes, thereby minimizing the effects of a poor maneuver. The disadvantage of a parking-orbit rendezvous is that it tends to be long and drawn out.

GEMINI and early APOLLO rendezvous flight plans used the parking-orbit rendezvous for two reasons: (1) GEMINI spacecraft did not have a navigation filter, so the final phase was planned to allow easy crew monitoring. Early APOLLO rendezvous flight plans followed the GEMINI experience; (2) uncertainty about the reliability of the new APOLLO system favored the smaller maneuver magnitudes of parking-orbit rendezvous in order to minimize the effects of a single bad burn.

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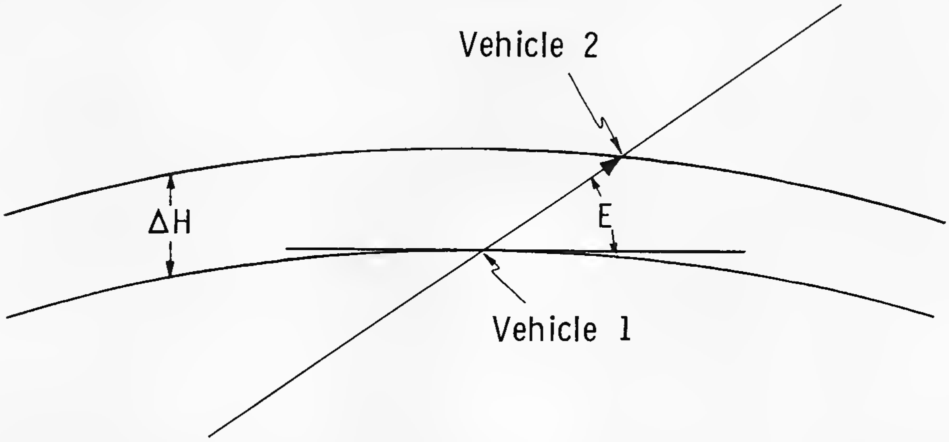
*P31 and P36 apply to CMC only.

Any parking-orbit rendezvous must eventually target a direct transfer to intercept. The difference is that a parking-orbit rendezvous sets conditions for a standardized transfer. The onboard capability for parking orbit rendezvous, known as the coelliptic sequence of maneuvers (P32 and P33), usually involves two parking orbits. The two maneuvers are designed to result in an orbit that (1) is coelliptic—that is, has a constant altitude differential—and (2) has a particular phase-angle—altitude-differential relationship defined by a particular elevation angle (E):



The first maneuver in the coelliptic sequence is designed to obtain the proper phasing, i.e., the correct E after the subsequent coelliptic maneuver; the second maneuver produces the coelliptic orbits. Coelliptic orbits, together with the proper E, produce the following desirable conditions: (1) closing rates are slow; (2) astronaut takeover is very easy in the event of computer malfunction; (3) errors can be discovered quickly by monitoring the elevation-angle changes.

Transfer to intercept, whether or not it is done in the context of parking-orbit rendezvous, simply involves planning the time and place of intercept and aiming to hit the spot at the proper time. P34 targets such trajectories; P35 targets midcourse corrections to such trajectories.

Figures 5.1-1 and 5.1-2 illustrate typical rendezvous profiles from two points of view. Figure 5.1-1 is a moon-centered inertial plot, and Figure 5.1-2 is a relative plot in a curvilinear coordinate system.* The following typical phase angles are also included in Figure 5.1-1:

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*Figure 5.1-2 was prepared by the Orbital Procedures Section for MSC Internal Note No. CF-R-69-26.

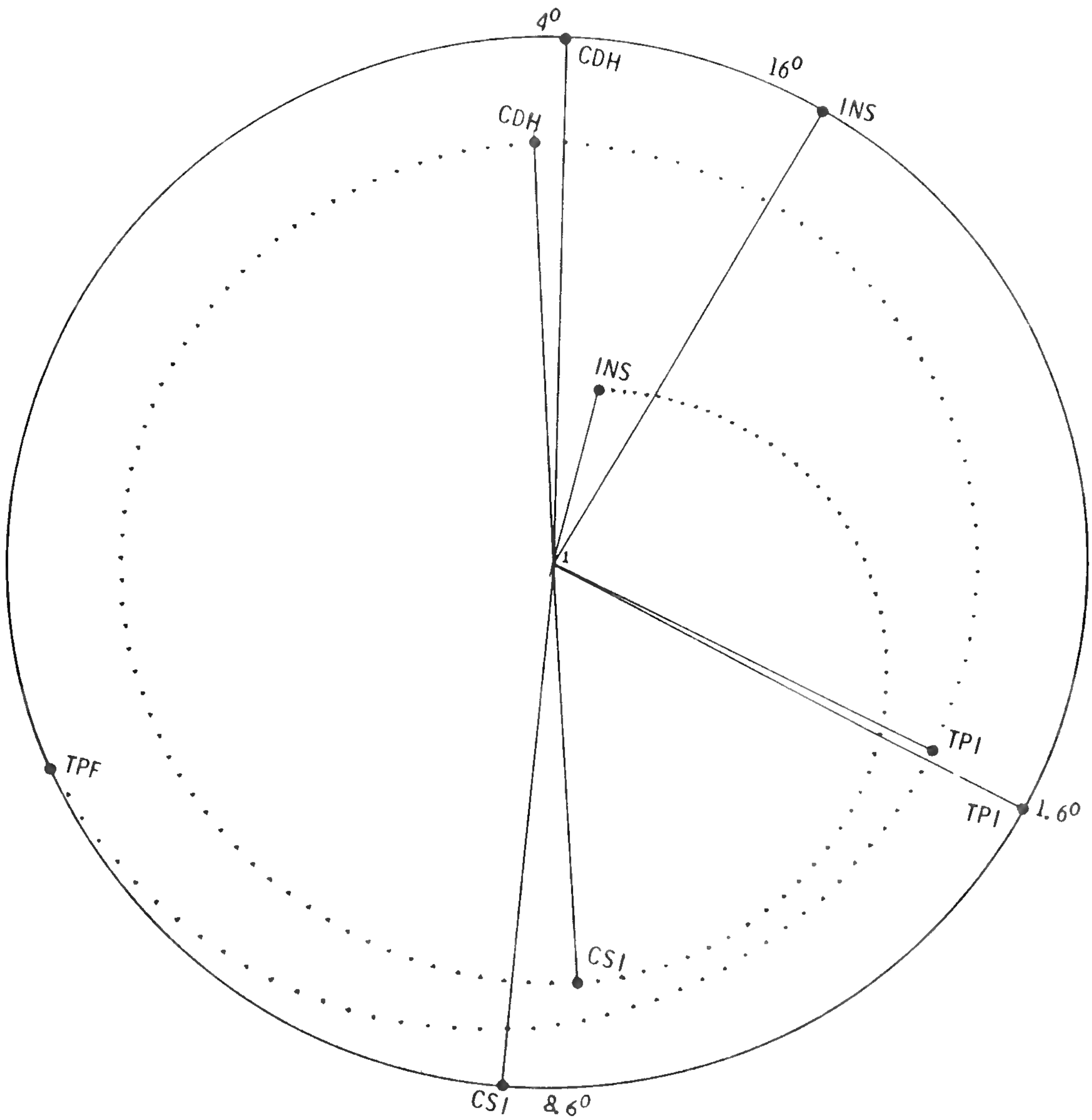
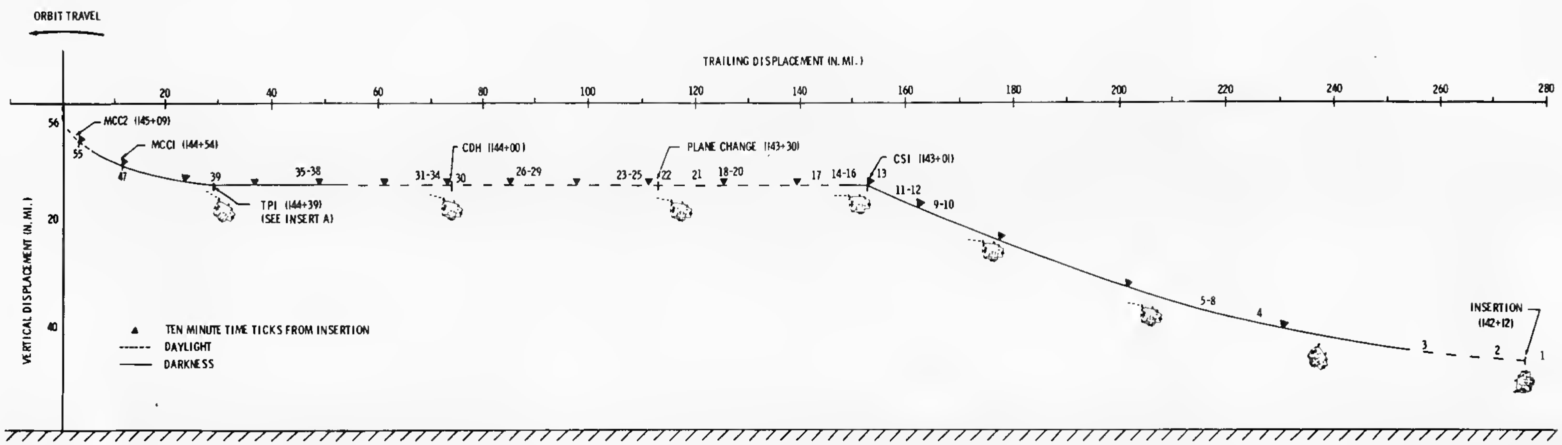


Figure 5.1-1. Moon-centered Inertial Plot Showing the Nominal G-Mission Rendezvous



LM MAJOR EVENTS

	GROUND ELAPSED TIME	EVENT		GROUND ELAPSED TIME	EVENT
1.	142+12	INSERTION	29.	143+52	AGS FINAL CDH COMP
2.	142+13	AGS TARGET CSI	30.	144+00	CDH THRUSTING MANEUVER (P41)
3.	142+16	IMU REFSMMAT ALIGN (P52)	31.	144+02	REINITIALIZE W-MATRIX (V93)
4.	142+25	INITIALIZE W-MATRIX (10000, 10, 15)	32.	144+03	RESUME RR NAVIGATION
5.	142+26	INITIATE RR NAVIGATION (P20)	33.	144+03	TARGET TPI (PGNCS P34 AND AGS)
6.	142+26	PGNCS TARGET CSI (P32)	34.	144+05	RESUME AGS RADAR UPDATES
7.	142+27	AGS UPDATE AND ALIGN	35.	144+27	TERMINATE RR NAVIGATION (24 MARKS)
8.	142+28	INITIATE AGS RADAR UPDATES	36.	144+27	PGNCS FINAL TPI COMP
9.	142+49	TERMINATE RR NAVIGATION (23 MARKS)	37.	144+30	TERMINATE AGS RADAR UPDATES (9 UPDATES)
10.	142+49	PGNGS FINAL CSI COMP	38.	144+31	AGS FINAL TPI SEARCH COMP
11.	142+52	TERMINATE AGS RADAR UPDATES (9 UPDATES)	39.	144+39	TPI THRUSTING MANEUVER (P41)
12.	142+53	AGS FINAL CSI COMP	40.	144+41	REINITIALIZE W-MATRIX (V93)
13.	143+01	CSI THRUSTING MANEUVER (P41)	41.	144+41	RESUME RR NAVIGATION
14.	143+03	INITIALIZE W-MATRIX (2000, 2, 5)	42.	144+41	TARGET MCCI (PGNCS P35 AND AGS)
15.	143+04	RESUME RR NAVIGATION	43.	144+41	RESUME AGS RADAR UPDATES
16.	143+04	TARGET CDH (PGNGS P33 AND AGS)	44.	144+51	TERMINATE RR NAVIGATION (9 MARKS)
17.	143+07	RESUME AGS RADAR UPDATES	45.	144+51	TERMINATE AGS RADAR UPDATES (6 UPDATES)
18.	143+21	TERMINATE RR NAVIGATION (17 MARKS)	46.	144+51	PGNGS AND AGS FINAL MCCI COMP
19.	143+22	OBTAIN CSM ROOT FOR PLANE CHANGE	47.	144+54	MCCI THRUSTING MANEUVER (P41)
20.	143+22	EXTERNAL ΔV FOR PLANE CHANGE (P30)	48.	144+56	REINITIALIZE W-MATRIX (V93)
21.	143+24	TERMINATE AGS RADAR UPDATES (7 UPDATES)	49.	144+56	RESUME RR NAVIGATION
22.	143+30	RCS PLANE CHANGE MANEUVER (P41)	50.	144+56	TARGET MCC2 (PGNCS P35 AND AGS)
23.	143+31	REINITIALIZE W-MATRIX (V93)	51.	144+56	RESUME AGS RADAR UPDATES
24.	143+32	RESUME RR NAVIGATION	52.	145+06	TERMINATE RR NAVIGATION (9 MARKS)
24A.	143+32	RESUME AGS RADAR UPDATES	53.	145+06	TERMINATE AGS RADAR UPDATES (6 UPDATES)
25.	143+32	TARGET CDH (PGNCS P33 AND AGS)	54.	145+06	PGNCS AND AGS FINAL MCC2 COMP
26.	143+48	TERMINATE RR NAVIGATION (15 MARKS)	55.	145+09	MCC2 THRUSTING MANEUVER (P41)
27.	143+48	PGNCS FINAL CDH COMP	56.	145+12	BRAKING (P47)
28.	143+51	TERMINATE AGS RADAR UPDATES (7 UPDATES)			

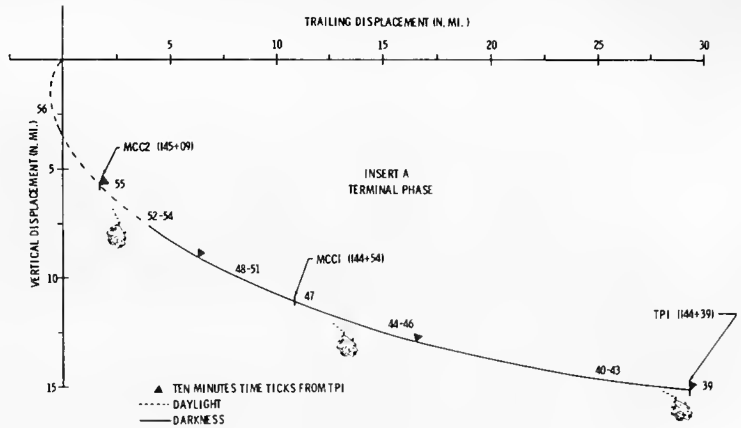


Figure 5. 1-2. H1 Mission Rendezvous; CSM-centered Motion

Insertion-CM,	16 deg ahead of LM
CSI-CM,	8.6 deg ahead of LM
CDH-CM,	4 deg ahead of LM
TPI-CM,	1.6 deg ahead of LM

In Figure 5.1-2, the vertical displacement is shown nearly constant from CSI to TPI. Thus, the orbits are nearly coelliptic before the CDH maneuver. In another flight plan, this need not be the case. In such an instance, the LM relative position plot would not be horizontal until after CDH.

During the transfer phase, the elevation angle for the LM (which can be drawn by connecting LM to CM, at the origin of the plot, and drawing a line through the LM position and parallel to the trailing displacement axis) can be seen to increase smoothly. This allows easy monitoring of rendezvous progress, as the elevation angle is quick to indicate targeting errors in the braking phase.

Accurate state vector estimates are most important during rendezvous. Because of this, all the rendezvous programs all designed to be used with Option 0 or 4 of the CM Universal Tracking and Rendezvous Navigation Program (P20, paragraph 4.2.1). For the LM Rendezvous Navigation Program (P20, paragraph 4.3.1). Marks can be incorporated during most displays, and each targeting program has special recycle capability that allows a preliminary estimate of the maneuver before navigation is completed.

5.1.3 Class 4 Maneuvers (P37)

The CM computer (CMC) has a capability of targeting a return-to-earth maneuver without the use of ground communication. With the exception of a small zone of no solution (nearly impossible to get to with the current flight plan), P37 will target for a return to the entry corridor from any time of ignition placing the spacecraft outside the lunar sphere of influence. The program is discussed in detail in paragraph 5.2.6.

5.1.4 Targeting Computations

The targeting programs can be classified by the type of maneuver targeted (either External Δv or Lambert) or by the method of computation (iterative or noniterative). For large maneuvers, External Δv does not rotate the spacecraft to follow a continuously redefined required velocity. This allows easy out-the-window monitoring. Therefore, all ground-targeted maneuvers are targeted in the External-Δv mode by P30.

Lambert maneuvers have two advantages, however, over External Δv maneuvers. The primary advantage of Lambert maneuvers is that the guidance is a closed loop, rather than an open loop. Further, the computer can take into account variations in the effects of gravity during the maneuver and adjust the commanded thrust direction accordingly. These advantages allow onboard targeting of large maneuvers in the AGC, which does not have the computer capacity or speed to precompute gravity variations, as required for large-maneuver External-Δv targeting. Accordingly, onboard-targeted return-to-earth maneuvers (P37) are in the Lambert mode. Rendezvous maneuvers (P31 through P36), however, are ordinarily of such small magnitude that the use of Lambert or External Δv was determined on the basis of ease of programing. (P31,** P32, P33, and P36** are External Δv; P34 and P35 are Lambert.)

Whether an iterative or noniterative method of computation is used depends, generally, on the extent that perturbations affect the solution. Since no analytic expression completely describes the forces acting upon a vehicle traveling between the earth and the moon, targeting of such a trajectory involves first an analytic approximation, then orbital integration to determine the error, a second approximation to compensate for the error, and so on, bracketing the solution until either an imposed iteration limit is reached or the approximation converges on the desired solution. Noniterative targeting should be used by P30, P33, P36, and, in lunar orbit, P34 and P35;* iterative targeting should be used by P31, P32, P37, and, when not in lunar orbit, P34 and P35.

An example of iterative targeting is the Lambert offset technique used with P34 and P35. Given a transfer time and two points in inertial space, Lambert allows an appropriate conic trajectory to be constructed between the two points. In P34, the first point is the active-vehicle position at TPI, the second point is the passive-vehicle position at intercept, and the transfer time is the transfer time of the passive-vehicle trajectory between TPI and transfer-phase final (TPF). The AGC computes the second point and the transfer time based on a stored central angle of transfer (CENTANG) and on a stored ignition time (t_{IG}).

Since Lambert calculations ignore such perturbations as oblateness, however, it is recommended that P34 target as follows when the spacecraft are in earth orbit (i.e., R1 of NOUN 55 = 2) (refer to Figure 5.1-3):

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*P33 does iterate to find t_{IG}(TPI), but not to target for $\Delta \underline{v}$ (CDH). See paragraph 5.2.3.

**P31 and P36 apply to CMC only.

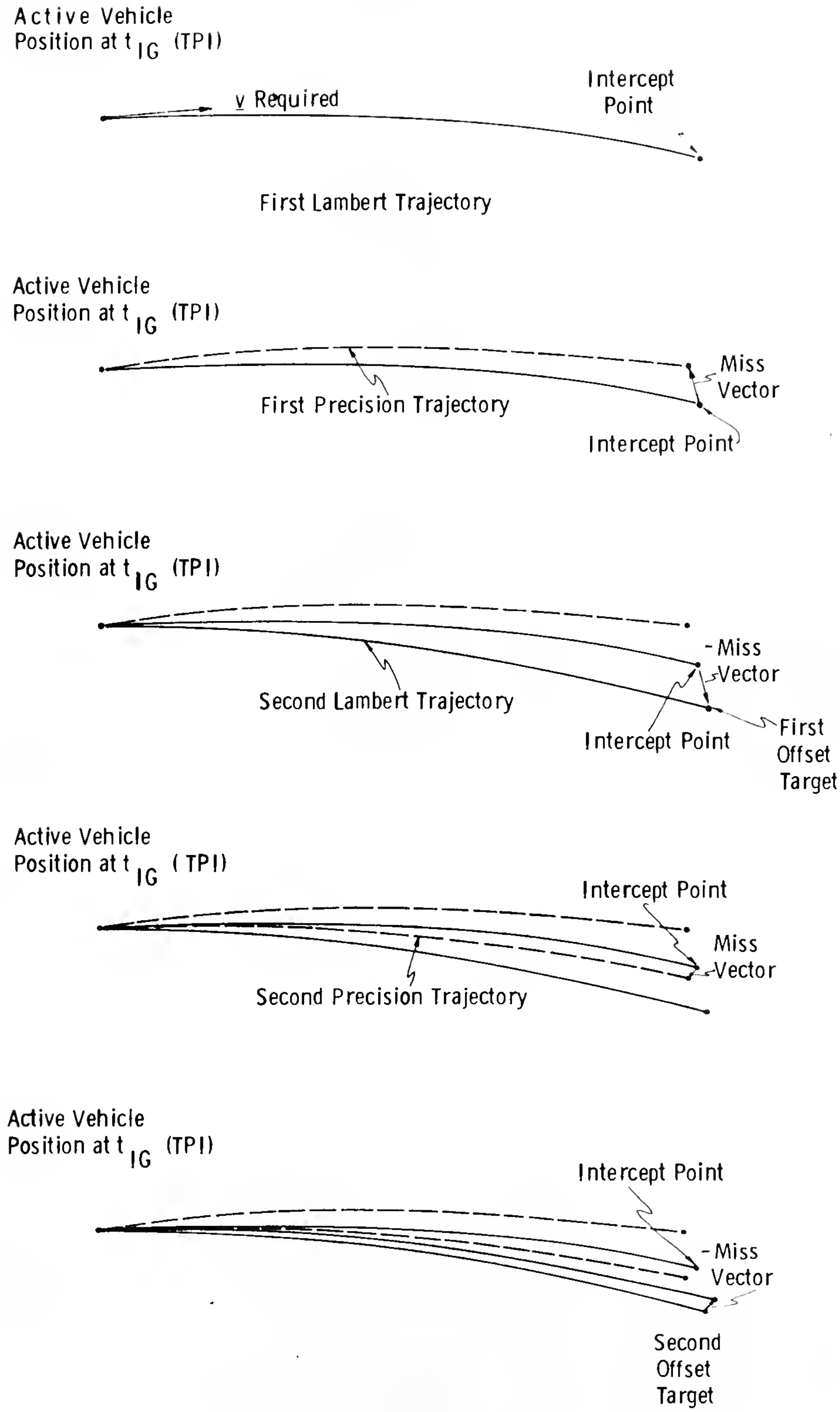


Figure 5.1-3. An Example of Lambert Offset Targeting

1. Passive-vehicle position vector is precision extrapolated to intercept time.
2. A Lambert solution ($\Delta \underline{v}$ at t_{IG}) is calculated for a conic trajectory that will obtain intercept.
3. Based on the Lambert solution, the AGC extrapolates a precision trajectory, incorporating perturbations, through the specified transfer time.
4. The resulting miss vector (the precision-extrapolated vector minus the Lambert target vector) is subtracted from the initial target vector in order to produce the <u>first offset</u> target.
5. A Lambert solution for the offset target is calculated, as in step 2.
6. Based on the new Lambert solution, a second precision trajectory is extrapolated.
7. The resulting miss vector is subtracted from the first offset target to produce a <u>second</u> offset target.
8. Steps 4 through 6 are repeated until a specified number of offsets have been targeted (usually two in earth orbit).

In lunar orbit, where the effect of perturbations is minimal, Lambert targeting is modified as follows. Instead of a precision extrapolation as in step 1, the passive-vehicle position vector is extrapolated to intercept time by the conic method. The Lambert solution (step 2) is then produced, and, since the effect of perturbations is small, the errors in the two conic trajectories tend to cancel. This eliminates the need for iterative offsets.

A similar offset procedure is used in P37. The Return to Earth Program must produce the correct flight-path-angle (FPA) at the correct altitude, rather than a particular position at a particular time (as in P34). The procedure for P37 is as follows:

1. P37 first calculates a conic solution ($\Delta \underline{v}$ at t_{IG}) that would, ignoring perturbations, obtain the entry FPA at the proper altitude (400,000 ft above the Fischer ellipsoid), or offset altitude on subsequent iterations.
2. Using the $\Delta \underline{v}$ from step 1, the AGC extrapolates a precision orbit to the desired FPA.
3. The altitude existing at that point is compared with the desired altitude (400,000 ft).
4. Based on the miss in altitude, an offset target altitude for a new conic solution is produced.
5. Steps 1 through 4 are repeated, each iteration refining the offset, either until the precision-altitude converges to 400,000 ft or until an iteration limit is reached.

5.1.5 Local-vertical Coordinates

All the targeting programs display their solution in local-vertical coordinates. Local-vertical (LV) coordinates have their origin in the spacecraft; they rotate as the spacecraft revolves around the central body. The +Z(LV) axis lies along the line-of-sight (LOS) from the spacecraft to the central body. $\underline{Z}$(LV) defines the local horizontal plane: any line through the spacecraft and perpendicular to $\underline{Z}$(LV) lies in the horizontal plane. The unitized projection of the vehicle velocity vector into the horizontal plane determines $\underline{X}$(LV). $\underline{Y}$(LV) completes a right-handed system: that is, it is to the right, as one faces forward along $\underline{X}$(LV). In other words, the CM body axes coincide with LV axes when the vehicle is oriented heads up, wings level, facing forward, with the Z body axis parallel to the local vertical. In the LM (un-docked), the body axes are rotated 90 deg, such that, for a heads-up, facing-forward (out the window), wings-level, X-body-parallel-to-local-vertical orientation, the correlation is as follows:

X-body = -Z(LV)
Z-body = X(LV)
Y-body = Y(LV)

Vehicle velocity is divided between the X(LV) and Z(LV) directions. For elliptic orbits, the majority of the velocity lies in the X(LV) direction. At apsidal crossings (i.e., for apogee or perigee crossings), the Z(LV) component of velocity is zero. If the vehicle is less than 180 deg before apogee, the Z(LV) component of velocity is positive. In a circular orbit, the Z(LV) component of velocity is always zero. For hyperbolic orbits, the X(LV) component of velocity approaches zero as the vehicle gets farther from the central body, but the Z(LV) component of velocity is still zero at perigee.

Figure 5.1-4 is a diagram of an elliptic orbit that illustrates how LV coordinates rotate, and how the vehicle velocity vector takes on various amounts of a Z(LV) component, being zero at the apsides.

It can be seen that vehicle velocity, when expressed in LV coordinates, will always have a zero Y(LV) component, because $\underline{Y}$(LV) is perpendicular to the orbital plane of transfer. After an out-of-plane maneuver, when the Y component of the change in velocity in LV coordinates—Δv(LV)—is nonzero, the LV coordinate system rotates such that the Y(LV) component of vehicle velocity is again zero. The following discussion illustrates the role of LV coordinates in achieving a coplanar rendezvous configuration.

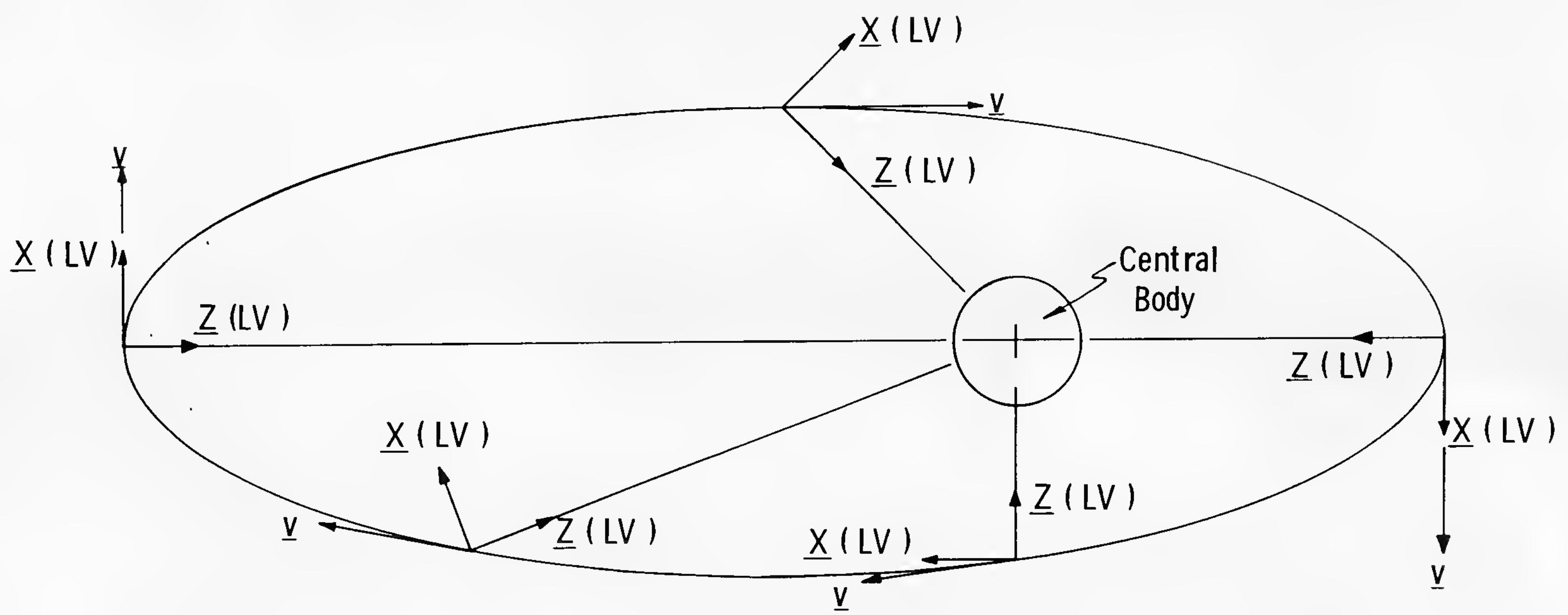


Figure 5.1-4. Rotation of Local-vertical Coordinates

Figure 5.1-5 shows two orbits that are out of plane with respect to each other. Nodes denote intersection of one orbit with the plane of the other (only incidentally do orbits themselves intersect) and occur twice a revolution for two noncoplanar orbits. A plane-change maneuver with the proper change in velocity at a node will produce coplanar orbits. Antinodes are points where out-of-plane distance is at a maximum. Note that the antinodes are 90 deg from the nodes.

Vehicle 2 is at an antinode. Vehicle 2's velocity vector ($\underline{v}_2$) is parallel to the plane of transfer of vehicle 1. Vehicle 1 is approaching a node. Vehicle 1's velocity ($\underline{v}_1$) has a component (Y-dot_1) perpendicular to the plane of vehicle 2.

When vehicle 1 reaches the nodal point n_2, Y-dot_1 will be at a maximum. Suppose vehicle 1 does a maneuver at its current position that adds the following $\Delta\underline{v}$ (LV) to $\underline{v}_1$:

$$\Delta\underline{v} = -\text{Y-dot}_1\ \underline{Y}_1\ (\text{LV}),$$

where $\underline{Y}_1$ (LV) = Unit Vector of Y(LV) axis of vehicle 1.

Now Y-dot_1 = 0, since it was nulled out; hence, vehicle 1 is at an antinode. Since vehicle 1 has been made to be at an antinode, i.e., the point where the thrust occurs is the new antinode, a new node can be expected 90 deg later. An examination of Figure 5.1-6 shows this to be the case. If Y-dot_1 is nulled at the new node, then the vehicles will be coplanar.

There is a slight discrepancy in this logic: the $\Delta\underline{v}$ <u>should</u> be $\Delta\underline{v} = -\text{Y-dot}_1\ \underline{Y}_2$ (LV). For the small Y values occurring during APOLLO rendezvous, this discrepancy is usually negligible. If Y-dot is nulled during CSI or CDH, the discrepancy does not exist. (See paragraphs 5.2.3 or 5.2.2.)

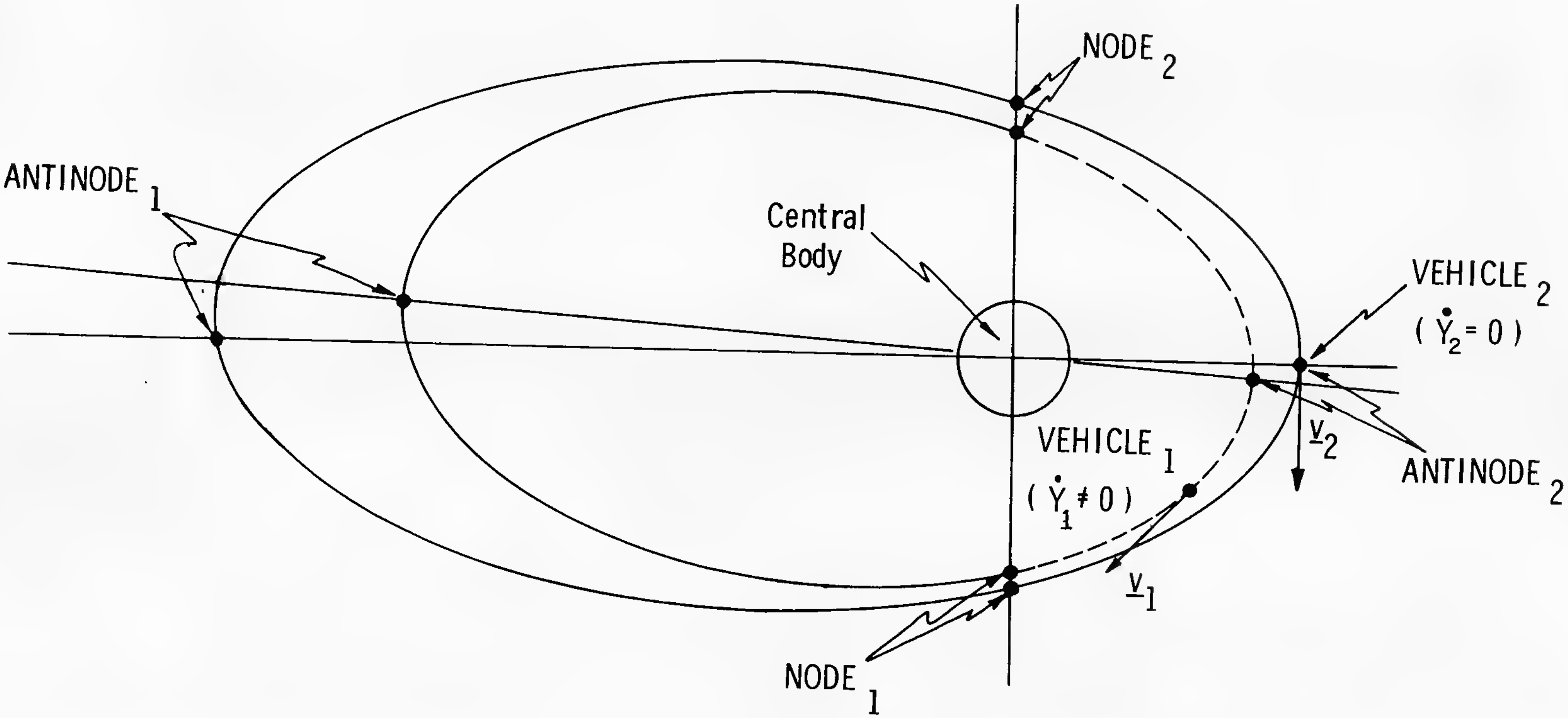
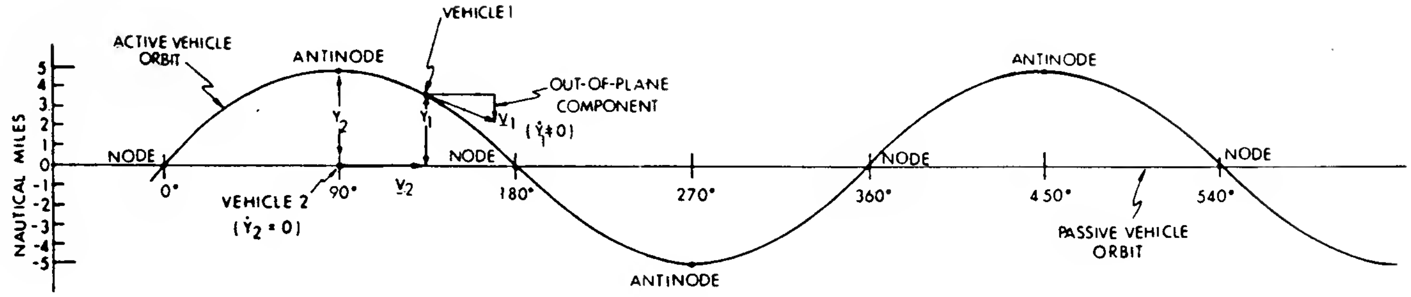
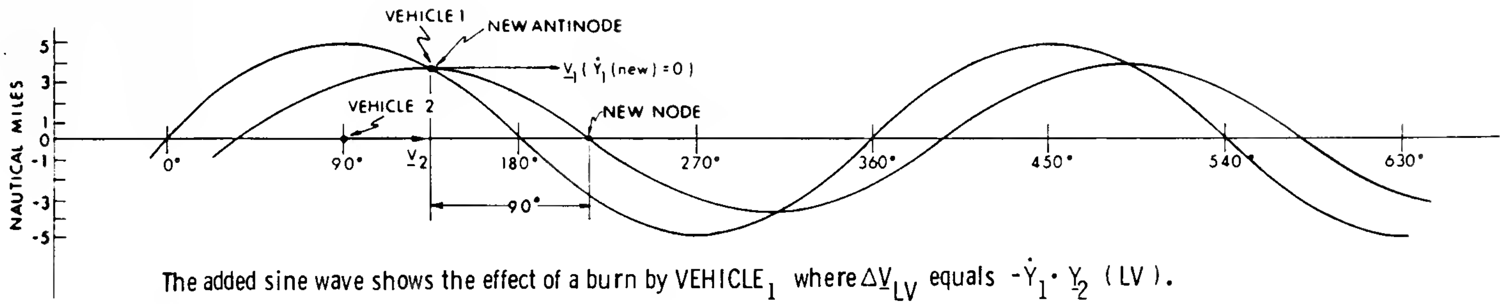


Figure 5.1-5. Non-Coplanar Orbits



In the above figure, the orbital plane of $VEHICLE_2$ is represented by the horizontal axis. The sine wave represents the displacement of the orbital plane of $VEHICLE_1$



The added sine wave shows the effect of a burn by $VEHICLE_1$ where $\Delta \underline{V}_{LV}$ equals $-\dot{Y}_1 \cdot \underline{Y}_2$ (LV). Note that the period remains the same but the magnitude is diminished

Figure 5.1-6. Example of the Effects of an Out-of-plane Maneuver

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5.2 CMC TARGETING PROGRAMS

This subsection contains descriptions of individual CMC programs used in targeting (1) external Δv maneuvers (paragraph 5.2.1); (2) CSM-active rendezvous retrieval maneuvers (paragraphs 5.2.2–5.2.5, plus 5.2.12 and 5.2.13); and (3) return-to-earth maneuvers (paragraph 5.2.6). In addition, CMC-targeted LM-active maneuvers are described in paragraphs 5.2.7–5.2.10; the CMC LM Target Δv Program is described in paragraph 5.2.11; and the program for telling the CMC that the CM has performed a non-AVERAGEG-monitored maneuver is described in paragraph 5.2.14. For LGC targeting programs, refer to subsection 5.3.

The CSM-active rendezvous retrieval programs (P31–P36) are used in concert with Options 0 and 4 of the Universal Tracking and Rendezvous Navigation Program (P20, paragraph 4.2.1) to target powered-flight maneuvers described in subsection 6.2. Program sequencing, comprising navigation, targeting, plane-change alignment, thrusting, and rendezvous final phase, is described in paragraph 4.2.1.2. In the Minimum Keystroke (MINKEY) mode of P20, sequencing of navigation, targeting, thrusting, etc., is accomplished automatically. This is described in paragraph 4.2.1.2.6, where Table 4.2.1-IV presents a chronology of DSKY procedures for an entire rendezvous sequence.

> NOTE.—MINKEY sequencing can only be used with CSM-active targeting programs (P31–P36).

The present nominal (direct) rendezvous trajectory calls for maneuvers targeted by the Transfer Phase Initiation Program (P34) and the Rendezvous Midcourse Maneuver Program (P35). (See Figure 5.2-1.) For rendezvous conditions when a direct rendezvous cannot be made without first adjusting the phasing between the active and passive vehicles, the Concentric Flight Plan is still available. The Concentric Flight Plan (CFP) comprises

1) Coelliptic Sequence Initiation—targeted by P32 (CSM active) or P72 (LM active),
2) Constant Differential Altitude—targeted by P33 (CSM active) or P73 (LM active),
3) Transfer Phase Initiation—targeted by P34 (CSM active) or P74 (LM active),
4) Midcourse Maneuver—targeted by P35 (CSM active) or P75 (LM active).

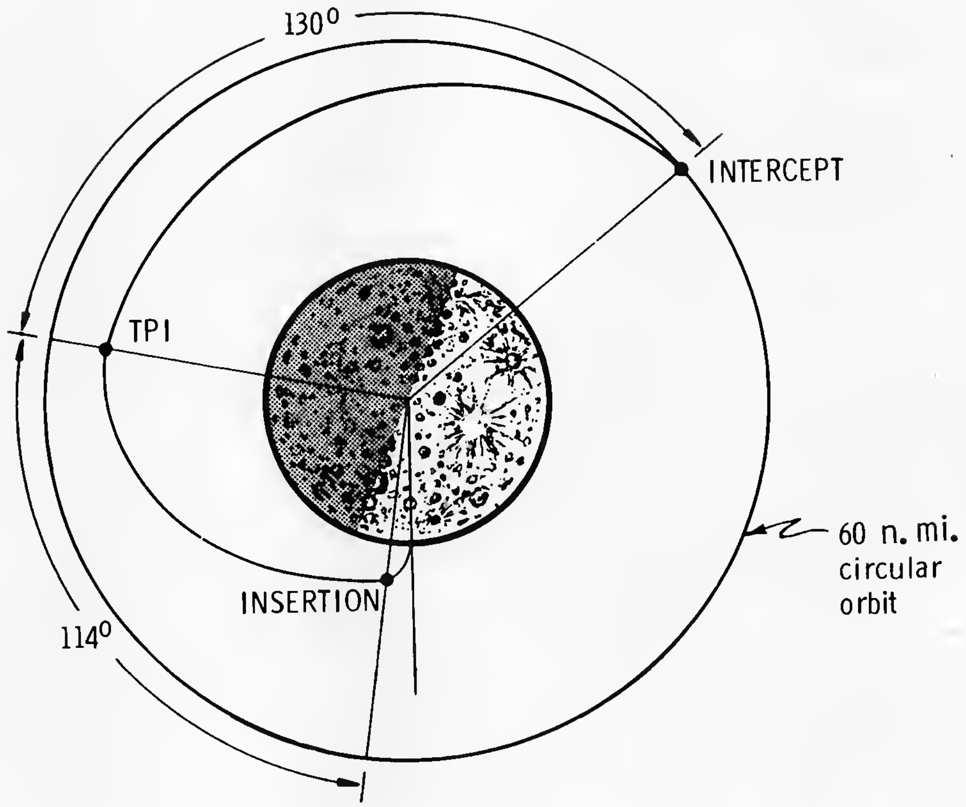

Figure 5.2-1. Direct Rendezvous Profile

Two additional CMC programs—Plane Change Maneuver (targeted by P36) and Height Adjustment Maneuver (targeted by P31)—are now available for use in the following CFP, CSM-active conditions:

1. When a plane-change maneuver is required to effect coplanar active- and passive-vehicle orbits before CDH (see paragraph 5.1.5), a P36-targeted PC maneuver can be performed 90-deg after CSI.
2. When CSM height adjustment is required in order that the standard coelliptic differential altitude will be attained after the CDH maneuver, a P31-targeted maneuver can be performed 180 deg before CSI. An example of when this might be necessary is following a LM abort during powered descent.

Neither P31 nor P36 have their LM-active counterparts, since the maneuvers would only be performed during a CSM-active CFP rendezvous.

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5.2.1 P30, External Δv—CMC

The purpose of P30 is to enable an external Δv maneuver to be targeted in local vertical coordinates, to initialize certain registers for P40/P41, and to display parameters related to an external Δv maneuver. The program can be used either with an uplinked t_{IG} and velocity-change vector, to accomplish a plane-change maneuver calculated by R36, or with input in local-vertical coordinates from any other source. Figure 5.2.1-1 is a flowchart of P30.

5.2.1.1 P30 Assumptions

The assumptions under which P30 operates and a brief explanation of each follow:

1. The above-mentioned t_{IG} and velocity-change vector have been uplinked via P27 or has been input from some other source.
2. If this is an uplinked burn, then concurrent with the operation of P27, a PAD has been voiced up from the ground.
3. The ISS need not be running or aligned for P30 to run to completion.
4. If P30 is run during rendezvous, the Rendezvous Mode of P20 can continue to run and marks can be incorporated during the first two flashing displays.
5. If the burn is ground-targeted, P30 is keyed in with sufficient time to allow for ground confirmation of displayed burn parameters.

5.2.1.2 Discussion of Inputs and Outputs

Tables 5.2.1-I and 5.2.1-II delineate P30 inputs and outputs, respectively. Noteworthy explanations of these inputs and outputs are given below.

If the maneuver is uplinked and any of the inputs or outputs are out of tolerance with the PAD voiced up from the ground, either the ground computer or the CMC has a bad state vector, or is malfunctioning. The burn should be postponed until new parameters can be uplinked, or the computer malfunction is diagnosed and corrected. If all outputs agree, within tolerances, with the PAD, or if the maneuver is on-board calculated to correct out-of-plane conditions, PRO should be used for inputs 1 and 2 and outputs 1, 2 and 3. Output 4, VHF and optics marks, is a part of NOUN 45, the exit display for all targeting programs, and is relevant only if P30 is used during the rendezvous sequence. Output 5, time from ignition, is self-explanatory.

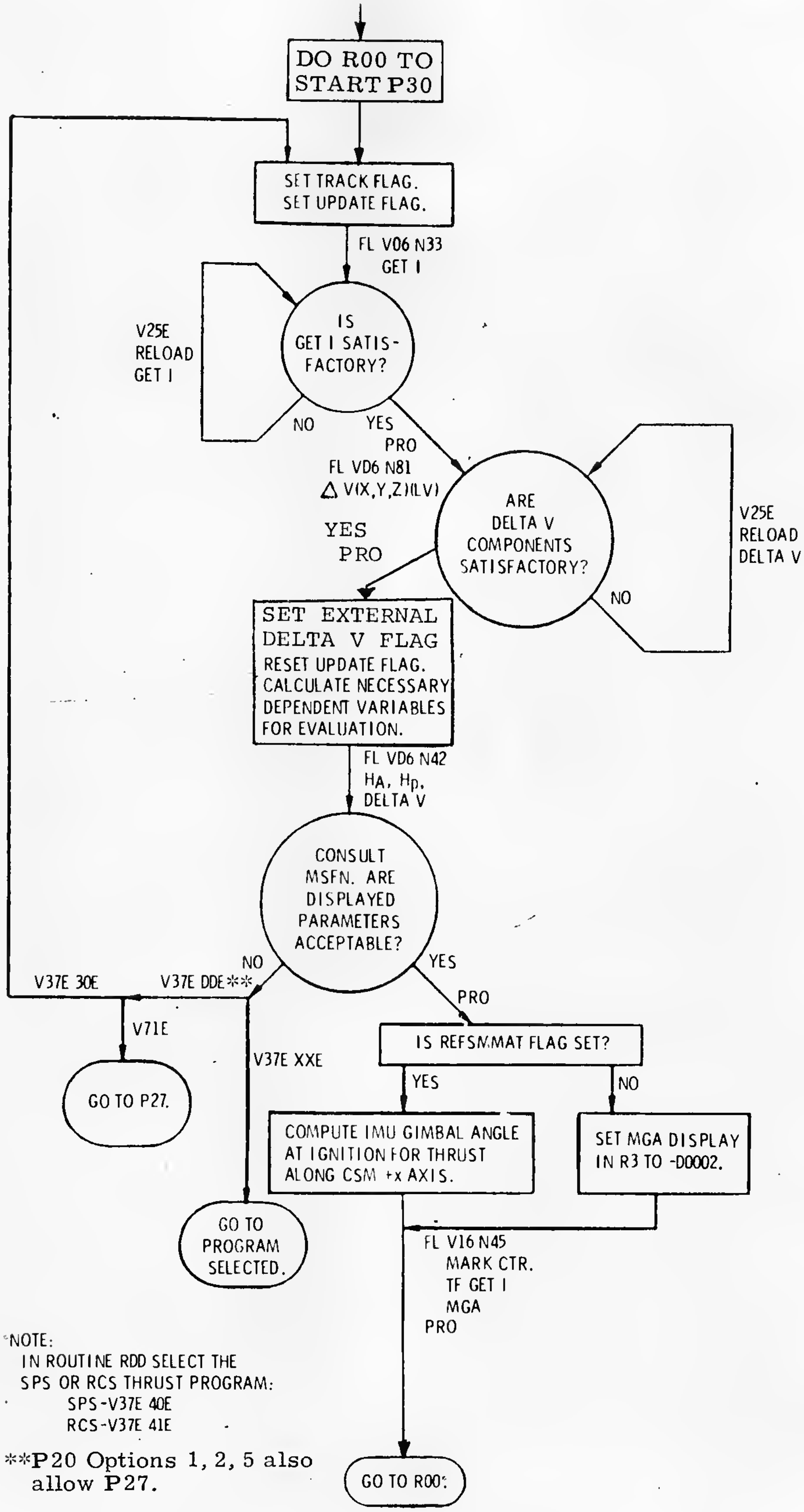

Figure 5.2.1-1. External Δv Program (CSM P30)

TABLE 5.2.1-I

EXTERNAL Δv INPUTS (CSM P30)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time of ignition	TIG	FL V06 N33	R1 ooxxx. hr R2 oooxx. min R3 oxx.xx sec	If the burn is uplinked, these registers will display the uplinked t_{IG}. If an onboard-calculated out-of-plane maneuver is being targeted then T(EVENT) must be loaded.
2.	Impulsive velocity change vector	DELTA V(LV)	FL V06 N81	R1 xxxx.xfps X R2 xxxx.xfps Y R3 xxxx.xfps Z	If the burn is uplinked, these registers will display the uplinked $\Delta \underline{v}$ (LV).

TABLE 5.2.1-II

EXTERNAL Δv OUTPUTS (CSM P30)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Apogee altitude above pad radius/latest landing site radius	APO ALT	FL V06 N42	R1 xxxx.x n. mi.	Maximum number (9999.9), if scaling is exceeded.
2.	Perigee altitude above pad radius/latest landing site radius	PER ALT	FL V06 N42	R2 xxxx.x n. mi.	Maximum number (9999.9), if scaling is exceeded.
3.	Magnitude of velocity change	DELTA V	FL V06 N42	R3 xxxx.x fps	
4.	Rendezvous marks taken	MARK-COUNT	FL V16 N45	R1 xxBxx VHF marks taken, optics marks taken	
5.	Time from ignition	TFI	FL V16 N45	R2 xxBxx min, sec	Maximum reading, 59 min, 59 sec; negative before t_{IG}, positive after t_{IG}.
6.	Middle gimbal angle	MGA	FL V16 N45	R3 xxx.xx + degrees if alignment of of IMU is known. -00002, otherwise.	

If R3 in NOUN 45 (output 6) indicates an excessive MGA (perhaps greater than 70 deg), the astronaut should consider realignment. If the ISS is not running, or if its alignment is unknown (in both instances, output 6 equals -00002), it must be powered up, and/or aligned before the burn. After the computer has received a PRO response to VERB 16 NOUN 45, P30 exits via R00 (flashing VERB 37).

Note that although P30 was once used for determining orbital parameters, especially for translunar and transearth coast, VERB 82 has now supplanted that function.

WARNING: The calculation of the apogee and perigee of the orbit resulting from the P30-targeted maneuver is based on an impulsive Δv, and can be very wrong for maneuvers of long duration.

If either P40 or P41 is keyed in after a P30-targeted burn, and then P30 is again keyed in (for the same burn), input 2 [DELTA V(LV)] should be reloaded with the original value, since P40/P41 rotate this vector through a central angle and then store it back in the original location eliminating the unrotated vector.

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5.2.2 P32, Coelliptic Sequence Initiation—CMC

P32 is part of the coelliptic sequence (P32 plus P33) of rendezvous targeting. The coelliptic sequence is designed to result in orbits in which the difference in altitude between the two orbits is nearly constant. Once coelliptic orbits have been achieved, the transfer phase (P34 plus P35) follows. This phase is designed to effect an intercept trajectory and a braking maneuver, allowing docking by the pilot of the active vehicle. Maneuvers to correct out-of-plane conditions can be made at any time in the rendezvous sequence. (See Figure 5.2.2-1.)

Two thrusting maneuvers make up the coelliptic sequence, the CSI (coelliptic sequence initiation) maneuver and the CDH (constant delta height or altitude) maneuver. P32 computes a horizontal maneuver for CSI parallel to the plane of the passive vehicle at the astronaut-specified t_{IG} (CSI). (Maneuver will not be parallel to the passive vehicle plane if astronaut exercises overwrite option described below.)

The magnitude and direction of this maneuver depend on four factors:

a. The state vectors of the two vehicles at t_{IG} (CSI)
b. The astronaut-specified time for the transfer phase initiation (TPI)*
c. CDH apsidal crossing (or 180-degree option)
d. The line-of-sight elevation angle (E).**

With Option 0 or 4 of P20 operating in the background, the crew can accumulate navigation (Optics and VHF) marks until he requests a final targeting solution for the CSI maneuver. In the meantime, he can recycle as frequently as time permits for preliminary solutions. The solution comprises three components of velocity (Δv_X, Δv_Y, Δv_Z) inputs for the powered-flight program that performs the maneuver. The Δv_Y component is set by the program to equal the CSM out-of-plane velocity -(Y-dot$_{CSM}$) at CSI time of ignition. This produces an antinode (paragraph 5.1.5) 90 deg after CSI (CSM trajectory), where a plane-change maneuver (targeted by P36) can be performed to effect coplanar orbits.

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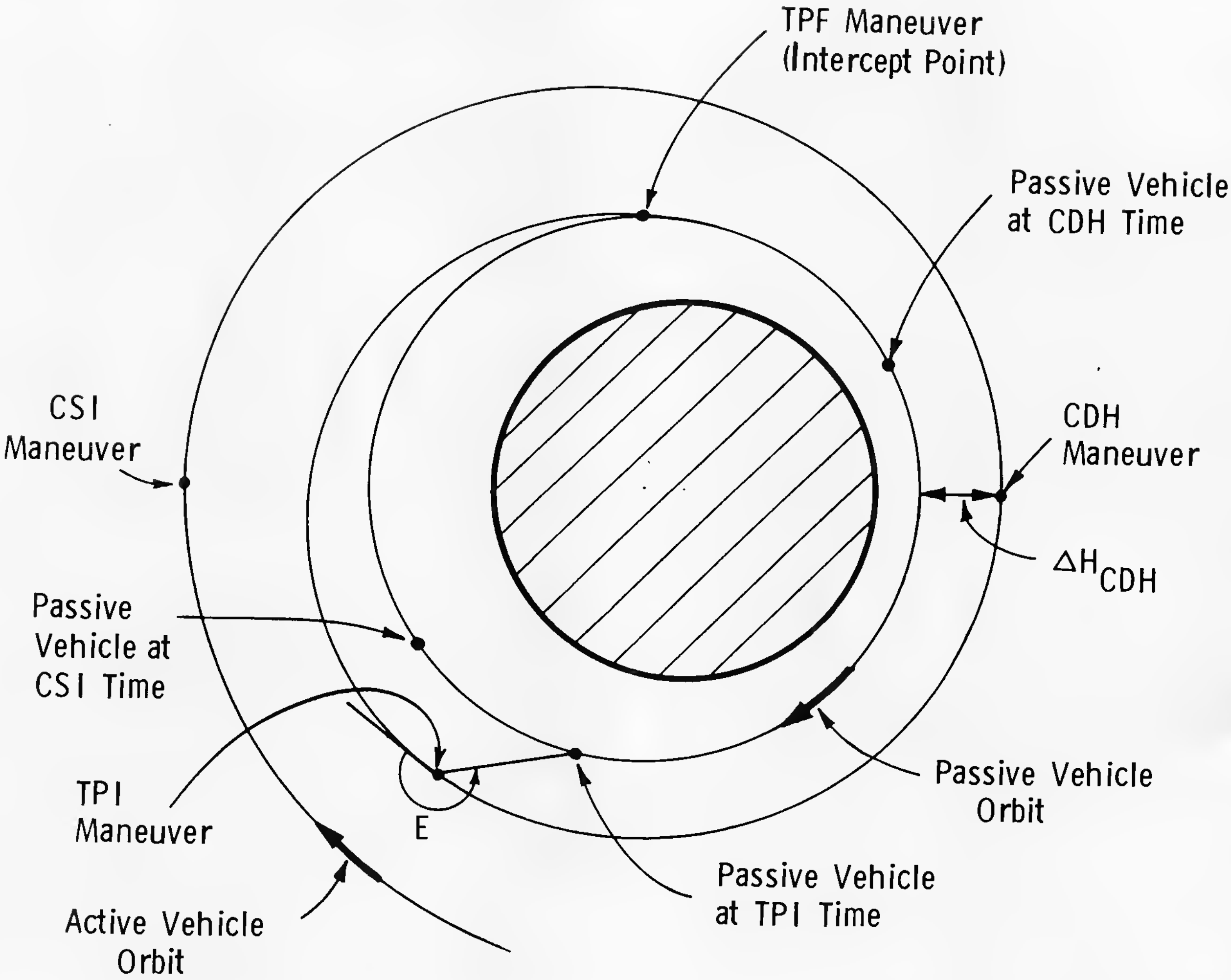
*t_{IG} (TPI) will usually occur at midpoint of darkness to allow good lighting conditions for final rendezvous.

**The line-of-sight elevation angle (E) allows the pilot of the active vehicle to boresight on the passive vehicle at t_{IG}(TPI). In this case, to boresight means that the thrust vector will be nearly coincident with the SXT LOS to the LM. As a backup to computer failure, the astronaut may thrust while holding the CM in the SXT LOS attitude.



NOTE: ΔH_{CDH} is not strictly LM altitude minus CSM altitude, but the altitude of the point on the LM orbit directly below the CSM at CDH, minus the CSM altitude. This distinction becomes significant when the passive vehicle is in a highly elliptical orbit and the central angle between the two vehicles at the CDH time is large. (This diagram is not in scale.)

Figure 5.2.2-1. An Example of a CSM-active Rendezvous Configuration

P32 contains an iteration loop, using the CSI Δv as the independent variable to obtain the specified TPI conditions. Under nominal flight configuration, the iteration scheme converges very quickly; the total final computation usually takes about 3 minutes. (See subsection 5.1 for a description of rendezvous trajectories and computations. Navigation is described in Section 4.0.)

5.2.2.1 Discussion of Inputs and Outputs

Figure 5.2.2-2 illustrates P32 functional flow. The following definitions apply:

TRACK and UPDATE flags refer to P20. If TRACK flag is set, tracking is allowed; if it is reset, tracking is not allowed. If UPDATE flag is set, the state vector may be updated from marks; if reset, the state vector may not be updated from marks.

REFSMMAT flag set means IMU alignment is known. If REFSMMAT flag is reset, IMU alignment is not known.

FINAL flag set indicates the astronaut has keyed in PRO in response to VERB 16 NOUN 45. FINAL flag reset indicates he has not.

Table 5.2.2-I lists the input displays, which all come at the beginning of P32. Under nominal conditions, program inputs are as indicated on the voiced-up PAD. If an alarm occurs or if the solution seems questionable, the inputs can be checked by keying the particular input NOUN. Recovery from alarms is described in paragraph 5.2.2.3.

Table 5.2.2-II lists P32 output. VERB 16 NOUN 45 shows the status of rendezvous navigation: R1 shows the number of marks incorporated since the last time the W-matrix was reinitialized; R2 shows how much time is left before ignition to take marks and perform final P32 computation; R3 indicates whether the CMC will accept marks. If R3 equals -00001, then final computations have not been made by the CMC and marks will be incorporated if taken during any flashing non-alarm display. If the astronaut wishes to terminate the marking process and use the current estimate of the state vector in the CMC, he should key PRO in response to a VERB 16 NOUN 45 display. After such a keystroke, no more marks will be incorporated by the CMC. The computer will calculate the burn parameters for a final time, display the various other outputs and then redisplay VERB 16 NOUN 45. At this time, the IMU status is indicated in R3. If alignment is unknown, R3 equals -00002. Otherwise, the MGA at t_{IG}(CSI) will be shown as a positive number. Having once keyed PRO

as a response to VERB 16 NOUN 45, a second PRO response* (when the display returns) will terminate the program via Routine 00. (Recycling, using a VERB 32 ENTR response, is useless at this point because no parameters will change—no marks can be accepted.)

Output 4 (ΔH_{CDH}) is critical to the operation of the pre-TPI routine called by P33 and P34. In particular, if the sign of ΔH_{CDH} is plus, indicating that the CM will be below the LM after CDH, then an E-angle of anything greater than 180 degrees will cause a 00611 alarm in P33 and P34. Such a situation is considered unlikely. Should it occur, sometime before final P33 computation the astronaut should key VERB 06 NOUN 55 ENTR and follow with the appropriate load verb to change E (in R2) to the value that the LM should use in a nominal TPI maneuver. (See subsection 5.2.4.)

If output 4 is small (less than about 5 n. mi. magnitude), the astronaut should be prepared for a possible 00611 alarm in P33 due to excessive iterations. It is possible that varying t_{IG}(CDH) will avoid such problems; therefore, if he expects such a problem, the astronaut should select P33 for preliminary calculations very soon after CSI to allow time for searching for a solution. (See paragraph 5.2.3.)

The other outputs of P32 are self-explanatory. The following facts, however, should be emphasized. The minutes part of output 5 and 6, DELTA T (CSI/CDH) and DELTA T (CDH/TPI), are displayed modulo 60. That is, if the minutes of either output 5 or output 6 are greater than 60, they are divided by 60 and the remainder is displayed. Thus, it is possible to see values in outputs 5 or 6 that appear to be less than 10 minutes, even though no alarm has been called. Simply remember that output 5 plus output 6 must equal the time interval between t_{IG}(CSI) and t_{IG}(TPI). If the result appears to be an hour or two less, then the above process has occurred.

5.2.2.2 Program Coordination

Final computations in P32 should come 9 to 12 minutes prior to t_{IG}(CSI). A minimum of 3 minutes should be allowed for final P32 computation. Final computation time could increase, however, with a poor orbital configuration. A poor configuration would exist when the LM is in an off-nominal orbit (after an abort, for instance). In such a case, a preliminary computation should be made as soon as possible to see if more time should be allowed for final P32 computation.

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*If MINKEY is active, W-Matrix reinitialization values are changed automatically to 2000 ft. and 2 ft/sec.

5.2.2.3 Procedures for Correcting Alarm Conditions

When an alarm occurs and the astronaut wishes to change some input variable, he should key VERB 32 ENTR and use the appropriate load verb when the proper display comes up. In all cases, upon occurrence of an alarm display from P32, the first source of error to be considered should be bad input. The astronaut should check (by keying the NOUN containing the input in question) and then recycle (VERB 32 ENTR).

> NOTE.—VERB 32 ENTR causes the inputs to be initialized to their preset values. If these have been overwritten by the crew, the new values can only be checked before recycling.

Other possible sources of alarms are poor orbital configuration and bad estimates of state vectors in the CMC. If the estimates of state vectors contained in the CMC are believed to be bad, procedures should be followed to correct the situation. (See paragraph 4.2.1.) The following paragraphs assume good input conditions and good CMC state vector estimates.

All alarm codes are part of flashing display VERB 05 NOUN 09. A PRO response will do nothing; VERB 32 ENTR will recycle P32, allowing different inputs; VERB 34 ENTR will force the program to go to R00.

A list of alarm codes and procedures that may allow the program to run to completion follows:

a. Alarm code 00600 may occur if the E-angle line-of-sight from the active vehicle at TPI does not intersect the circle formed by the passive vehicle's radius at TPI.
b. Alarm code 00601 may occur if the post-CSI pericenter altitude is insufficient.
c. Alarm code 00602 may occur if the post-CDH pericenter altitude is insufficient.
d. Alarm code 00603 may occur if there is insufficient time between t_{IG} (CSI) and t_{IG} (CDH).
e. Alarm code 00604 may occur if there is insufficient time between t_{IG} (CDH) and t_{IG} (TPI).
f. Alarm code 00605 may occur if excessive iterations are occurring—without convergence.
g. Alarm code 00606 may occur if two successive iterations occur with a Δv greater than 1000 fps.

Alarm 00600 occurs if the active vehicle is so high relative to the passive vehicle at TPI, that it would be impossible to see the other vehicle with the given E-angle. This particular alarm will not occur in P72, using the same inputs, so one solution is to make the other vehicle do the CSI maneuver. (If that is done, however, it is conceivable that alarm 00601 or 00602 will occur, and a ground targeted maneuver will be required.) Increasing TPI time of ignition by one orbit, and increasing N by 1 or 2 may also help. One last possibility is to advance TPI time in 15-minute increments on successive cycles of P32. This violates the precondition that TPI be in the midpoint of darkness, but it may work.

Alarm codes 00601 and 00602 will generally occur when the active vehicle is forced to go into a lower orbit to catch up in phasing with the passive vehicle. The astronaut can try any of the following: increase TPI time, modify N, have the other vehicle perform the CSI maneuver, request a phasing maneuver of ground.

Alarm code 00603 can always be avoided by using the 180-degree option (input 4 nonzero).

Should alarm 00604 occur, recycle and use the 180-degree option. Should the alarm occur again, increase the TPI time by one orbital period, retaining the 180-degree option.

Alarm 00605 is unlikely to occur. Should it occur, however, either recycle with a different N, usually increasing N by 1, or move the whole sequence up by one orbital period.

Alarm code 00606 may occur if Δt (CSI/TPI) is too small for a given configuration. Increasing TPI time should lower the Δv.

5.2.2.4 Restarts

P32 is restart protected.

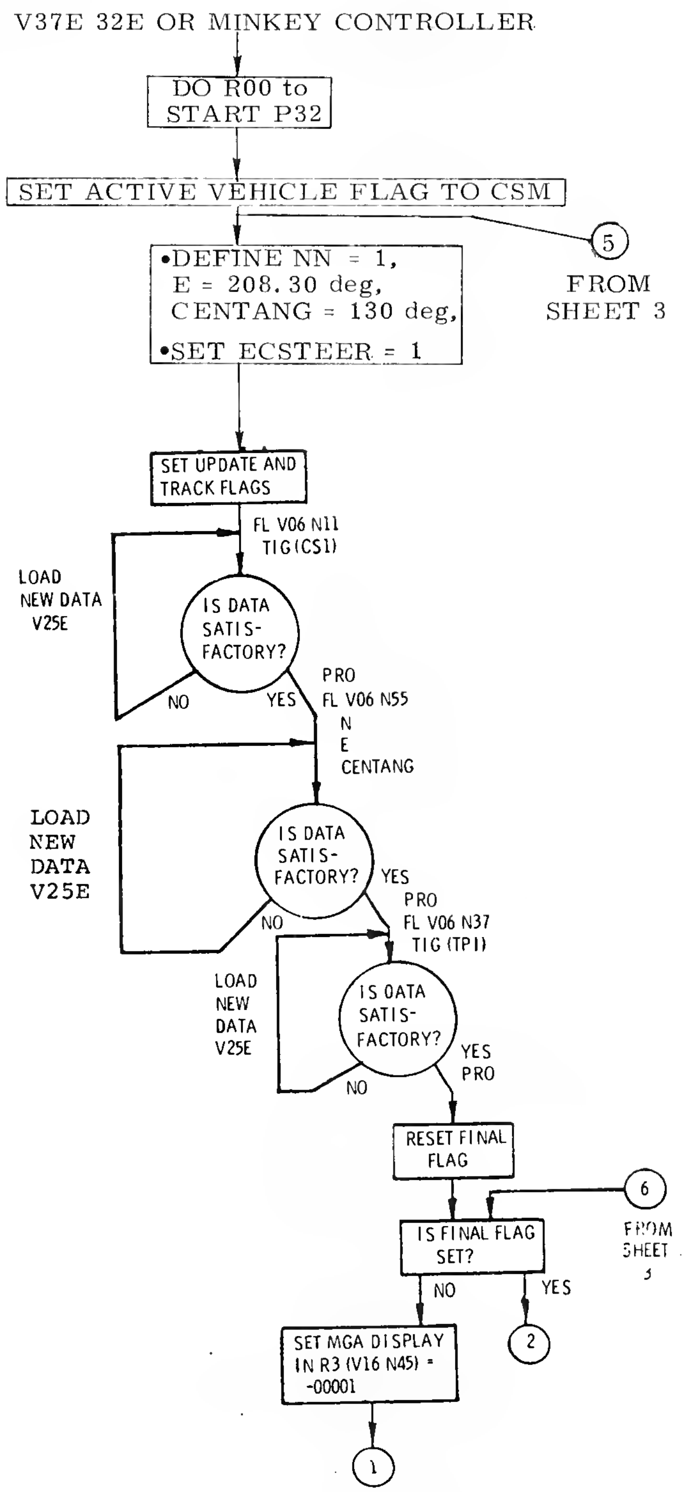


Figure 5.2.2-2. Coelliptic Sequence Initiation (CSI) (CSM P32) (Sheet 1 of 3)

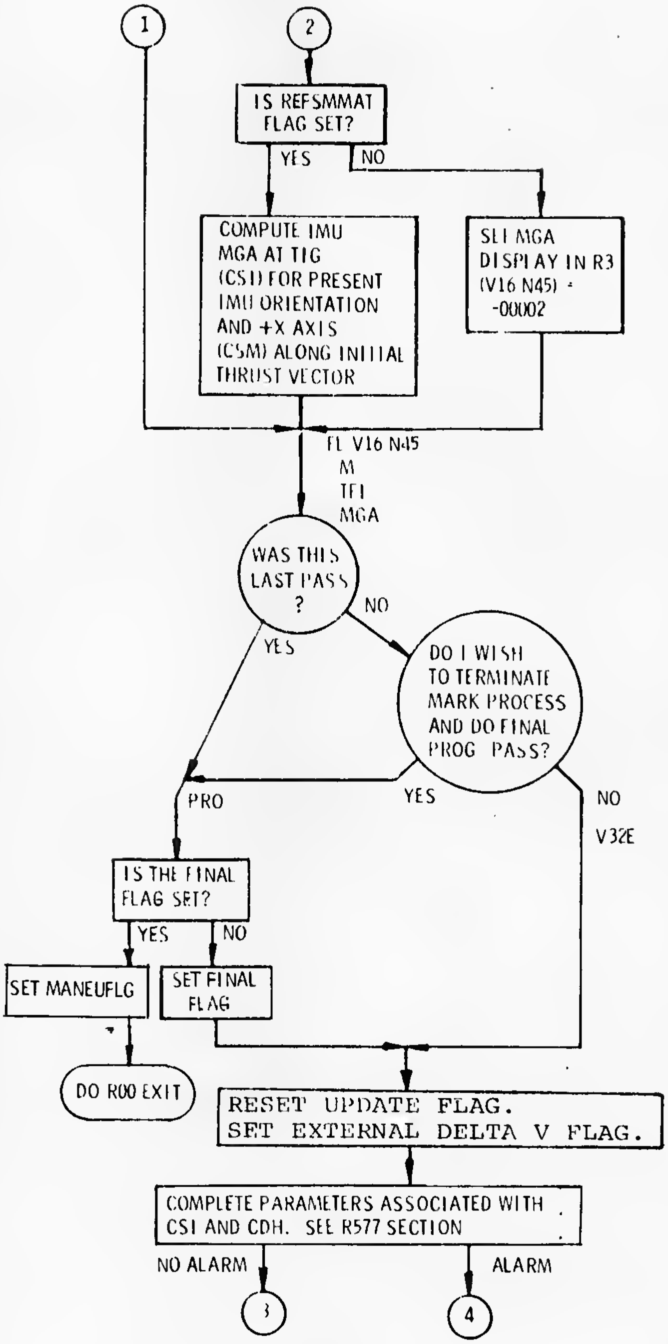
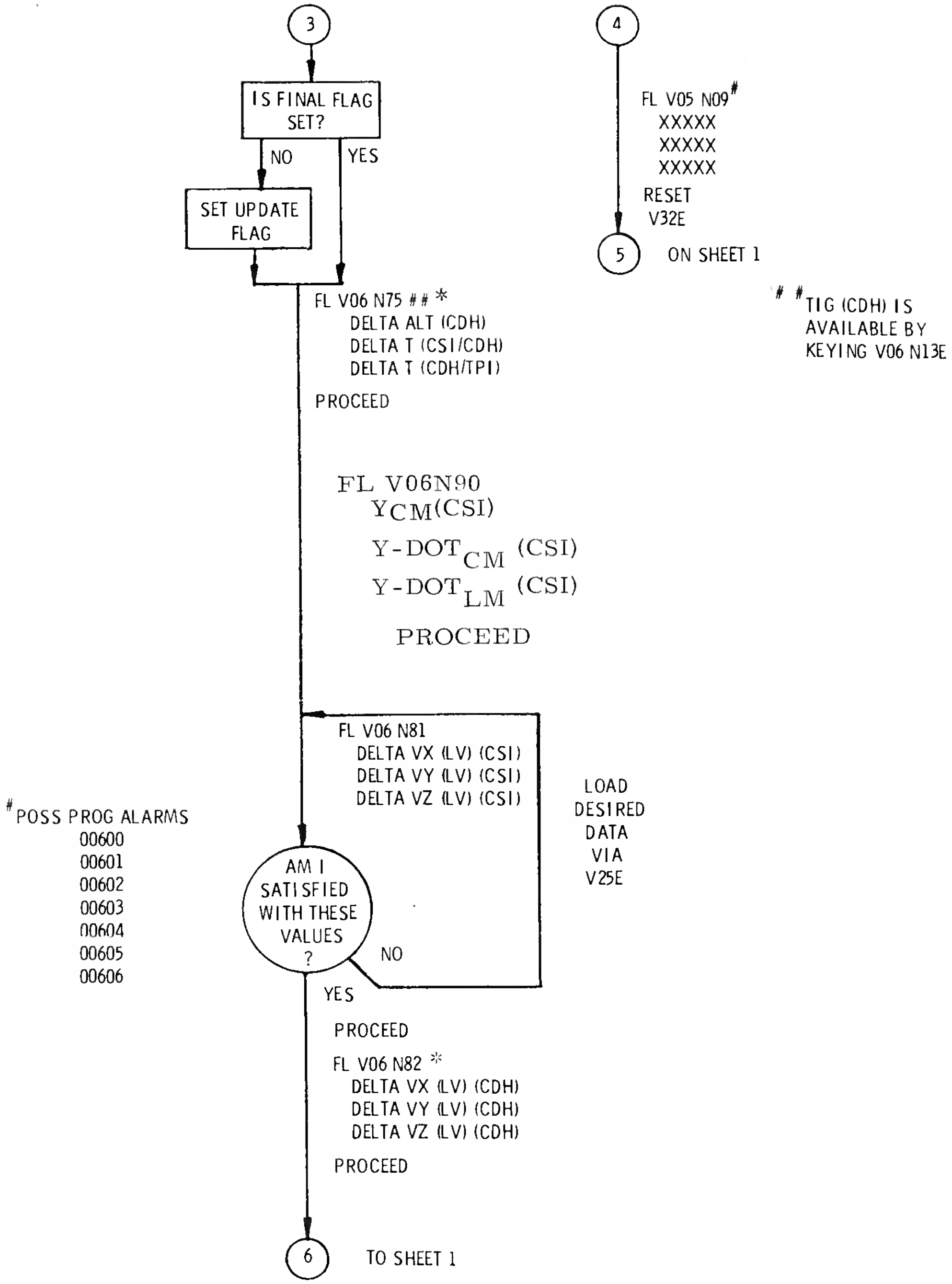


Figure 5.2.2-2. Coelliptic Sequence Initiation (CSI) (CSM P32)
(Sheet 2 of 3)



* NOT DISPLAYED DURING MINKEY

Figure 5.2.2-2. Coelliptic Sequence Initiation (CSI) (CSM P32) (Sheet 3 of 3)

TABLE 5.2.2-I

P32 (CSM) PROGRAM INPUTS (SHEET 1 OF 2)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time of CSI ignition	TIG(CSI)	FL V06N11	R1 ooxxx. hr R2 oooxx. min R3 oxx.xx sec	Astronaut must load TIG(CSI) if P32 is being called for the first time. If, however, P32 is entered from a multiple-CSI condition during MINKEY or from P31 the t_{IG} displayed here will be correct for the upcoming CSI.
2.	The number of the post-CSI apsidal crossing of the active vehicle at which t_{IG}(CDH) should occur, or the integral multiple of 180° transfer angle at which t_{IG}(CDH) will occur.	N	FL V06N55	R1 00001 Unless changed by astronaut	The nominal value of N for execution of the CFP is 1. There are planned abort situations which involve more than one CSI maneuver. In these cases the value of N is greater than 1 determined by the ground or charts. See paragraph 4.2.1.2.6.1 for description of N during MINKEY.
3.	Elevation angle. The angle between the CSM/LM LOS and the CSM local horizontal, referenced to the direction of flight. (See R577, Section 5.4.2, Figure 4.2-3.)	E	FL V06N55	R2 208.30 deg Unless changed by astronaut	The passive vehicle can be boresighted at this angle for TPI burn. While changing E might eliminate some alarms, E should remain constant, as all chart solutions depend on a particular E-angle.
4.	180-degree option	CENTANG	FL V06N55	R3 130.00 deg Unless changed by astronaut V23ENTR	Loading any non-zero value into R3 will produce a CDH burn at a transfer angle from CSI of N times 180 deg.

TABLE 5.2.2-I

P32 (CSM) PROGRAM INPUTS (SHEET 2 OF 2)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
5.	Time of TPI ignition	TIG(TPI)	FL V06 N37	R1 ooxxx. hr R2 oooxx. min R3 oxx.xx sec	Astronaut must load t_{IG} (TPI). t_{IG} (TPI) minus t_{IG} (CSI) ought to be at least 70 minutes for lunar orbit, when the 180-degree option is used. An absolute minimum would be 25 minutes. If N is increased, t_{IG} (TPI) must be increased

NOTE: The astronaut should terminate all these input displays with a PRO keystroke. If at any time the astronaut wishes to change the displayed values, he may load new ones by first keying in the appropriate load verb.

TABLE 5.2.2-II

P32 (CSM) PROGRAM OUTPUTS (SHEET 1 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Accumulated Marks	Mark Counters	FL V16 N45	R1 xxBxx: VHF marks, Optics marks	VERB 32 ENTR starts computation process using latest update of state vector. PRO terminates mark process and starts final computation. See expanded commentary below.
2.	Time from ignition	TFI	FL V16 N45	R2 xxBxx: min, sec maximum: 59 min, 59 sec	Indicates time available for rendezvous navigation, execution time final P32 computation and burn preparation before t_{IG} (CSI).
3.	Middle gimbal angle (see comments at right)	MGA	FL V16 N45	R3 xxx.xx deg	-00001 indicates a PRO response to VERB 16 NOUN 45 has not been received. -00002 indicates a PRO response has been received, and the alignment of the ISS is unknown. +xxx.xx deg indicates a PRO response has been received and shows the (positive) MGA at TIG (CSI). A PRO response for a second time will allow the program to go to Routine 00.

TABLE 5.2.2-II

P32 (CSM) PROGRAM OUTPUTS (SHEET 2 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
4.**	Passive vehicle altitude minus active vehicle altitude at t_{IG} (CDH).	DELTA ALT (CDH)	FL V06N75	R1 xxxx.x n.mi.	Normal response to VERB 06 NOUN 75 is PRO.
5.**	t_{IG}(CDH) minus t_{IG}(CSI)	DELTA T(CSI/CDH)	FL V06N75	R2xxBxx: min, sec maximum: 59 min, 59 sec	Computed in hours, minutes, and seconds, of which only the minutes and seconds are displayed.
6.**	t_{IG}(TPI) minus t_{IG}(CDH)	DELTA T(CDH/TPI)	FL V06N75	R3 xxBxx: min, sec maximum: 59 min 59 sec	Computed and displayed same as output 5.
7.	Y_{CSM} out of plane position at T_{IG}(CSI)	Y_{CM}	FL V06 N90	R1xxx.xx n.mi.	
8.	$\dot{Y}_{CSM}$ out of plane velocity at T_{IG}(CSI)	$\dot{Y}_{CM}$	FL V06 N90	R2xxxx.x fps	$-\dot{Y}_{CSM}$ is the VY(LV) component of N81.
9.	$\dot{Y}_{LM}$ out of plane velocity at T_{IG}(CSI)	$\dot{Y}_{LM}$	FL V06 N90	R3xxxx.x fps	
10.	Impulsive v, in local vertical coordinates, for CSI	DELTA V(LV) (CSI)	FL V06 N81	R1xxxx.x fps X R2xxxx.x fps Y R3xxxx.x fps Z	Astronaut can change this vector by using VERB 25 ENTR.
11.**	Impulsive v, in local vertical coordinates, for CDH	DELTA V(LV) (CDH)	FL V06 N82	R1xxxx.x fps X R2xxxx.x fps Y R3xxxx.x fps Z	Calculation of DELTA V(LV) (CDH) assumes that the CSM was active at CSI.

* t_{IG}(CDH) is available by keying VERB 06 NOUN 13 ENTR.

** Not displayed during MINKEY but available by keying NOUN xx ENTR at FL V16N45 at end of computation cycle.

BLANK

5.2.3 P33, Constant Delta Altitude Targeting (CDH)—CMC

The Constant Delta Altitude (CDH) maneuver results in an active vehicle orbit that remains at a nearly constant radial distance from the passive vehicle orbit. A CDH maneuver is targeted after a CSI maneuver in order to set up conditions for the transfer phase. (Refer to paragraphs 5.2.2 and 5.2.4 for an explanation of the CSI and TPI maneuvers, respectively.) If a plane-change maneuver (targeted by P36) is required, it occurs between CSI and CDH (CSM trajectory). (Targeting trajectories and computations are described in subsection 5.1.)

P33 targets for a CDH maneuver, using a t_{IG}(CDH) supplied by the astronaut at the beginning of P33 and a t_{IG}(TPI)* and elevation angle (E) supplied by the astronaut at the beginning of P32.** In addition to targeting for CDH, P33 uses the pre-TPI routine to find the precise time when it will be possible to do a TPI maneuver, after CDH, using the desired E-angle. This allows the Command Module (CM) pilot to plan his post-CDH actions.

The targeting of the CDH maneuver within P33 is separate from the determination of the correct t_{IG}(TPI). Whereas a CDH maneuver is calculated simply by equalizing the velocities in the z-direction of the local vertical coordinate system (unless astronaut utilizes overwrite option (N90)), the pre-TPI routine takes the input t_{IG}(TPI) and uses it as an initial estimate in an iterative search for the precise time when the elevation angle coincides with the desired E-angle.

5.2.3.1 P33 Computational Sequence

After P33 is selected, it first enables tracking and mark incorporation by setting TRACK and UPDATE flags. Then the CM computer (CMC) flashes VERB 06 NOUN 13, which requests the astronaut to supply a t_{IG}(CDH) for the program. Under most circumstances (unless subsequently changed by the astronaut), the time displayed will be the t_{IG}(CDH) computed in P32. This value should only be used if the CM performed the CSI maneuver. If the LM performed the CSI maneuver, the LM t_{IG}(CDH) should be keyed in. The CMC will then flash VERB 16 NOUN 45,

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*If P32 has not been completed before P33—e.g., because of an alarm—the crew must load a t_{IG}(TPI) and E at the first VERB 16 NOUN 45 display. This is done by keying VERB 25 NOUN 37 ENTR and loading the desired time, and VERB 22 NOUN 55 ENTR and loading desired elevation angle.

**The CM pilot will probably use the t_{IG}(CDH) calculated by P32, if the CM performed the CSI maneuver. If the LM performed CSI, the CM pilot should use the t_{IG}(CDH) calculated by the LGC. Some alarm recovery procedures involve changing t_{IG}(CDH). (See paragraph 5. 2. 3. 4.)

which requests the astronaut to determine whether the next computation cycle will be a preliminary or final computation. The appropriate responses to flashing VERB 16 NOUN 45 are VERB 32 ENTR and PRO for a preliminary and a final computation, respectively.

After a response to VERB 16 NOUN 45, the CMC prevents any mark incorporation for the duration of the succeeding calculations by resetting the UPDATE flag. These calculations can be divided into two parts. The first involves the calculation of a maneuver that will make the active vehicle orbit coelliptic with the passive vehicle orbit. The second takes the resultant orbit, and attempts to find the time when the desired E-angle exists. In addition, the out-of-plane parameters at t_{IG}(CDH) are computed and displayed.

The first calculation is purely analytical, and simply calculates the Δv necessary to make the active vehicle H-dot—velocity along the local vertical at t_{IG}(CDH)—equal to the passive vehicle orbital H-dot; that is, the H-dot on the passive vehicle orbit at the intersection of the passive vehicle orbit and the line formed by the projection of the active vehicle's position vector into the passive vehicle's plane.

The second calculation is the pre-TPI routine. It uses the t_{IG}(TPI) input into P32 as an initial estimate in an iteration scheme to find the exact time when the desired E-angle exists. If the pre-TPI routine cannot find the required time, a VERB 05 NOUN 09 alarm is flashed; the alarm code is 00611. If no alarm occurs, or if PRO is keyed in response to the flashing VERB 05 NOUN 09 display, P33 proceeds to the next display (VERB 06 NOUN 75).* Before flashing this display, however, P33 determines whether the astronaut has keyed PRO in response to VERB 16 NOUN 45. If the FINAL flag is set, then he has keyed PRO; if reset, he has not, and P33 allows marks to be incorporated by setting the UPDATE flag. The VERB 06 NOUN 75* display—ΔH_{CDH}, Δt (CDH/TPI), Δt (TPI/TPI)—follows immediately, and is followed in turn by VERB 06 NOUN 90 (the out-of-plane parameters), then by VERB 06 NOUN 81 (the components of Δv). NOUN 81 (R2) will contain the (-) Y-dot$_{CSM}$ initially displayed in NOUN 90 (R2). Consequently, the Y-component of Δv will produce an antinode at t_{IG} (CDH) and a node 90 deg later (CSM trajectory).

The next display is VERB 16 NOUN 45. If the last computation completed was preliminary, the CM pilot will normally wait until a few more marks are incorporated before requesting a final computation. If the last computation completed was final, another PRO response to VERB 16 NOUN 45 allows the program to exit via R00.

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*Not displayed during MINKEY. (See paragraph 4.2.1.2.6.)

5.2.3.2 Input and Outputs

A flowchart, Figure 5.2.3-1, and two tables, Table 5.2.3-I and Table 5.2.3-II, summarize the operations of P33. The following definitions apply:

a. TRACK and UPDATE flags refer to P20 (Options 0 and 4). If TRACK flag is set, tracking is allowed. If reset, it is not allowed. If UPDATE flag is set, the state vector may be updated from navigation marks. If it is reset, no updating from marks is possible.

b. REFSMMAT flag set indicates that the IMU alignment is known; reset, it is unknown.

c. FINAL flag set indicates the astronaut has keyed PRO in response to VERB 16 NOUN 45. Reset means he has not. (Refer to paragraph 5.2.3.1.)

Table 5.2.3-II lists P33 output. Outputs 1, 2, and 3 are a part of VERB 16 NOUN 45, which shows the status of rendezvous navigation. R1 shows the number of marks incorporated since the last w-matrix reinitialization. R2 shows how much time is left before ignition to take marks and perform the final P33 computation. R3 indicates whether the CMC will accept marks or not. If R3 equals -00001, final computations have not been made by the CMC, and marks can be incorporated during any flashing display, except the alarm display. If the astronaut wishes to terminate the marking process and use the current estimate of the state vectors in the CMC, he should key PRO in response to a VERB 16 NOUN 45 display.

After PRO is keyed, no more marks will be incorporated into the state vector until reselection of a targeting program, and the CMC will calculate the maneuver parameters for a final time, display the other outputs, and redisplay VERB 16 NOUN 45. After a final computation, the IMU status is indicated in R3 of NOUN 45. If alignment is unknown, R3 equals -00002. Otherwise, the middle gimbal angle at t_{IG}(CDH) will be shown as a positive number. Once PRO has been keyed as a response to VERB 16 NOUN 45, keying a PRO again—as a second response*—will terminate the program via Routine 00. (A VERB 32 ENTR response at this point is undesirable because no parameters will change—that is, no marks will be accepted or incorporated.)

Output 4, ΔH_{CDH}, is the radial distance at CDH between the active vehicle and the passive vehicle orbit just above or below it. Output 4 is critical to recovery from alarm conditions. (See paragraph 5.2.3.4.)

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* If MINKEY is active W-Matrix reinitialize values are changed automatically to 2000 ft, and 2 ft/sec.

Output 5 is Δt(CDH/TPI). In trying to determine the correct t_{IG}(TPI), P33 first calculates the CDH maneuver parameters, and then extrapolates the post-CDH orbit. On the basis of that orbit, the pre-TPI routine searches for the correct t_{IG}(TPI). Using the computer mathematics, the post-CDH orbit can be extrapolated backwards in time, before CDH, as well as forward. It is conceivable that the proper E-angle might exist only before CDH, based on the post-CDH orbit. That is, if it were possible for the active vehicle to have been on the post-CDH orbit prior to CDH, then the proper E-angle would have existed at some time prior to CDH. Should this be the case, the computer will not be aware of the time difference, and will accept the indicated solution as a valid one. The astronaut can detect the occurrence of such a situation by observing output 5.

A negative output 5 indicates that P33 calculated TPI as coming before CDH. One of the conditions that P32 calculations must satisfy is that the time interval between CDH and TPI—Δt(CDH/TPI)—be greater than 10 minutes to allow time for rendezvous navigation after CDH. Output 5 of P33, however, can be negative, allowing no time for rendezvous navigation after CDH. Further, P33 accepts a negative solution as a valid solution. P33 also accepts an output 5 value of less than 10 minutes as a valid solution—a situation that would not provide sufficient navigation time. These situations might occur if CSI were poorly targeted, because of bad state vector estimates, or poorly executed. In any case, the CM pilot should carry out the CDH maneuver as targeted (assuming CSM-active) and select P34 with the time option (E equals 00000), with t_{IG}(TPI) set according to mission procedures.

The minutes part of positive outputs 5 and 6 —Δt(CDH/TPI) and Δt(TPI/TPI)—are displayed modulo 60. Negative values for output 5 are limited to a display of 59:59. A large Δt(TPI/TPI); i.e., a large difference between the input t_{IG}(TPI) and the calculated t_{IG}(TPI), usually means that Rendezvous Navigation after CSI has considerably changed the CMC estimate of the vehicle states. This large difference is likely to occur if CSI were poorly targeted or poorly executed.

5.2.3.3 Program Coordination

Program coordination when using P33 is straightforward. A preliminary calculation is usually made to get some idea of the maneuver characteristics; a final computation ought to be made 9 to 12 minutes before t_{IG}(CDH), according to mission procedures. P33 can run by itself (in which case the ISS need not be operating) or it can run in conjunction with Option 0 or 4 of P20 (in which case marks can be incorporated during any flashing display—except an alarm display—until final computation is

initiated by the astronaut by a PRO response to VERB 16 NOUN 45). The minimum time to allow for a final computation is 3 minutes.

Optimum targeting in P33 depends on relatively error-free estimates of the state vectors of the two vehicles with respect to each other. Ordinarily, there is ample time between CSI and CDH for P20 to reduce state vector errors. If optics marks are taken in batches, as is recommended when both the optics and the VHF are operating, P33 should be held at VERB 16 NOUN 45 until the end of a batch, and then a recycle or a final computation should be performed.

5.2.3.4 Alarms

Alarm code 00611 is the only alarm likely to occur during P33. Its occurrence indicates to the crew that the pre-TPI routine is unable to locate the time of existence of the proper E-angle. Figure 5.2.3-2 and Table 5.2.3-III summarize crew actions in response to a 00611 alarm.

In general, the recommended procedure in response to a 00611 alarm is for the CM pilot to attempt a correction of the alarm. The chart solutions, which depend on the correct E-angle at t_{IG}(TPI), will then be valid, and the rates and angles after TPI will be more familiar to the astronaut. If time does not permit an attempt at correction, rendezvous can be accomplished by keying PRO in response to the flashing VERB 05 NOUN 09 alarm display. This allows the program to terminate the current cycle without again searching for the proper t_{IG}(TPI). Another recycle or final computation will presumably cause another alarm, if no inputs are changed. The CM pilot should then perform the CDH maneuver as targeted (including any out-of-plane correction planned), and select P34, using the time option.

The following four circumstances could give rise to the 00611 alarm:

a. Excessive iterations because of small ΔH_{CDH}
b. Excessive iterations because the actual t_{IG}(TPI) is more than about 30 minutes from the input t_{IG}(TPI)
c. ΔH_{CDH} inconsistent with requested E
d. Active vehicle too high above the passive vehicle.

The astronaut can often foresee circumstances 1 and 3 by checking the output of P32. If output 1, ΔH_{CDH}, is less than 5 n. mi., or is of the wrong sign, the CM pilot should select P33 soon after CSI to check for alarm conditions.*

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* If E is greater than 180 deg, ΔH_{CDH} should be negative; if E is less than 180 deg, ΔH_{CDH} should be positive.

Circumstances 2 and 4 could only arise (assuming CDH is used as a part of the coelliptic sequence) from a poorly targeted (due to bad onboard state vector estimates) or a poorly executed CSI maneuver. The astronaut might suspect poor targeting and poor execution if IMU alignment is known to have been poor before CSI; if insufficient marks were taken before CSI; or if CSI is known to have been poorly executed. In any case, the CMC will assume that CSI targeting and execution went well, and will not give an alarm until rendezvous navigation has had time to modify the relative vehicle state vectors, bringing them more in line with the true situation. That is, the CMC can only be made aware of the fact that CSI was poorly targeted or executed by a period of rendezvous navigation after CSI. Without such navigation, a 00611 alarm will not arise from circumstances 2 and 4, in spite of the fact that the real situation might warrant such an alarm. Therefore, if P20 marking indicates a large state vector error by producing excessive updates after CSI, the CM pilot should be prepared for the occurrence of a 00611 alarm in P33.

Recovery procedures are different for each circumstance causing a 00611 alarm. It is, therefore, necessary first to determine the nature of the cause. As was mentioned above, output 1 from P32 should warn the CM pilot that ΔH_{CDH} is either too small, or is inconsistent with E. But poor targeting or execution of CSI could also have produced this anomalous ΔH_{CDH}. Therefore, even if ΔH_{CDH} appeared good in P32, these circumstances should not be excluded. The first action in an attempt to recover from alarm conditions, therefore, is to examine ΔH_{CDH}, the contents of R1 of NOUN 75.

If ΔH_{CDH} is inconsistent with E, then 180 deg should be added to E (displayed as R2 in NOUN 55) if E is less than 180 deg; 180 deg should be subtracted from E if E is greater than 180 deg.

If ΔH_{CDH} is consistent with E, but is less then 5 n. mi., the astronaut should recycle (VERB 32 ENTR) and subtract 5 minutes from t_{IG}(CDH), because, under most circumstances, the pre-CDH orbits are converging. If the alarm occurs again, ΔH_{CDH} should again be checked, to see if it is now larger or smaller than before. If it is larger, recycle and subtract another 5 minutes. If it is smaller, then the orbits are diverging, and a later t_{IG}(CDH) should be tried.

If ΔH_{CDH} is positive, greater than 5 n. mi., and consistent with E, then the actual t_{IG}(TPI) lies more than about 30 minutes from the input t_{IG}(TPI) supplied from P32. If ΔH_{CDH} is negative, indicating active vehicle above passive vehicle, greater than 5 n. mi., and consistent with E, then either t_{IG}(TPI) lies more than about 30 minutes from the input t_{IG}(TPI), or the active vehicle is too high above the passive

vehicle. By monitoring the progress of the program (via VERB 16 NOUN 38 ENTR), the astronaut can determine whether the active vehicle is too high above the passive vehicle (the program does not attempt to search for E under such conditions), or whether the actual t_{IG}(TPI) is too far before or after the input t_{IG}(TPI).

To describe how to monitor the program, it is first necessary to describe how the pre-TPI routine works. The pre-TPI routine accepts as input the active and passive vehicle state vectors, extrapolated to the input t_{IG}(TPI), the initial estimate used in the search for the actual t_{IG}(TPI). At this point, the alarm conditions of E, inconsistent with ΔH_{CDH} and active vehicle too high above the passive vehicle, are tested.

If these 2 tests are satisfied, the program first determines whether the correct E-angle exists before or after the given t_{IG}(TPI), and then proceeds to extrapolate the two vehicle state vectors, in steps limited to 250 sec, towards the time when the correct E-angle exists. This continues until the E-angle is reached.

When the CM pilot monitors P33, via VERB 16 NOUN 38, he will see the time associated with the vehicle state vectors. The displayed time, expressed in hours, minutes and seconds, will be augmented until the input TPI time is reached and the pre-TPI routine is entered. Then it will increase, if the actual t_{IG}(TPI) is after the input t_{IG}(TPI), or diminish if the opposite is true.

If the active vehicle is too high above the passive vehicle, or if E is inconsistent with ΔH_{CDH}, the program will not iterate after input t_{IG}(TPI) is reached. If ΔH_{CDH} is too small, the times will probably oscillate very soon after the input t_{IG}(TPI) is reached, and continue to oscillate for quite a while. If the actual TPI time is too far from the input TPI time, i.e., greater than approximately 30 minutes, then the displayed time will move quite far from the input t_{IG}(TPI) before oscillation begins.

If the active vehicle is too high relative to the passive vehicle, the CM pilot should recycle and augment t_{IG}(CDH), in an attempt to diminish ΔH_{CDH}. If an alarm occurs again, ΔH_{CDH} should be checked to see if it is smaller—in which case another recycle and a second augmentation of t_{IG} (CDH) is in order—or larger—in which case t_{IG} (CDH) should be diminished.

If actual t_{IG}(TPI) is far from input t_{IG}(TPI), the input t_{IG}(TPI), available in NOUN 37, should be moved in the direction of the actual t_{IG}(TPI).

5.2.3.5 Restarts

A restart that occurs during the operation of P33 will only cause a time loss (the maximum time loss is just less than the time required for final computation), not a loss of validity in the solution.

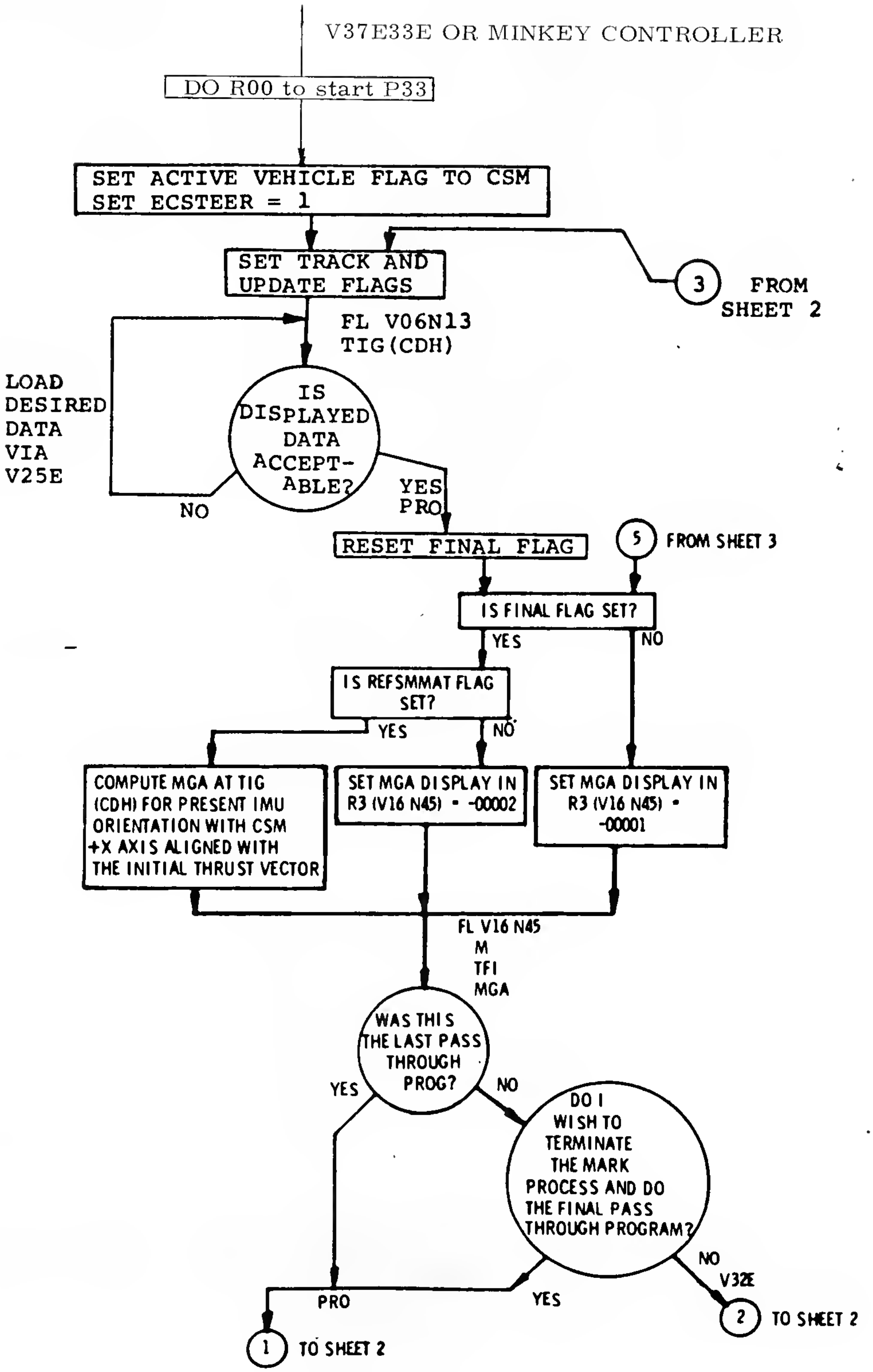


Figure 5.2.3-1. Constant Delta Altitude (CDH) Program (CSM P33) (Sheet 1 of 3)

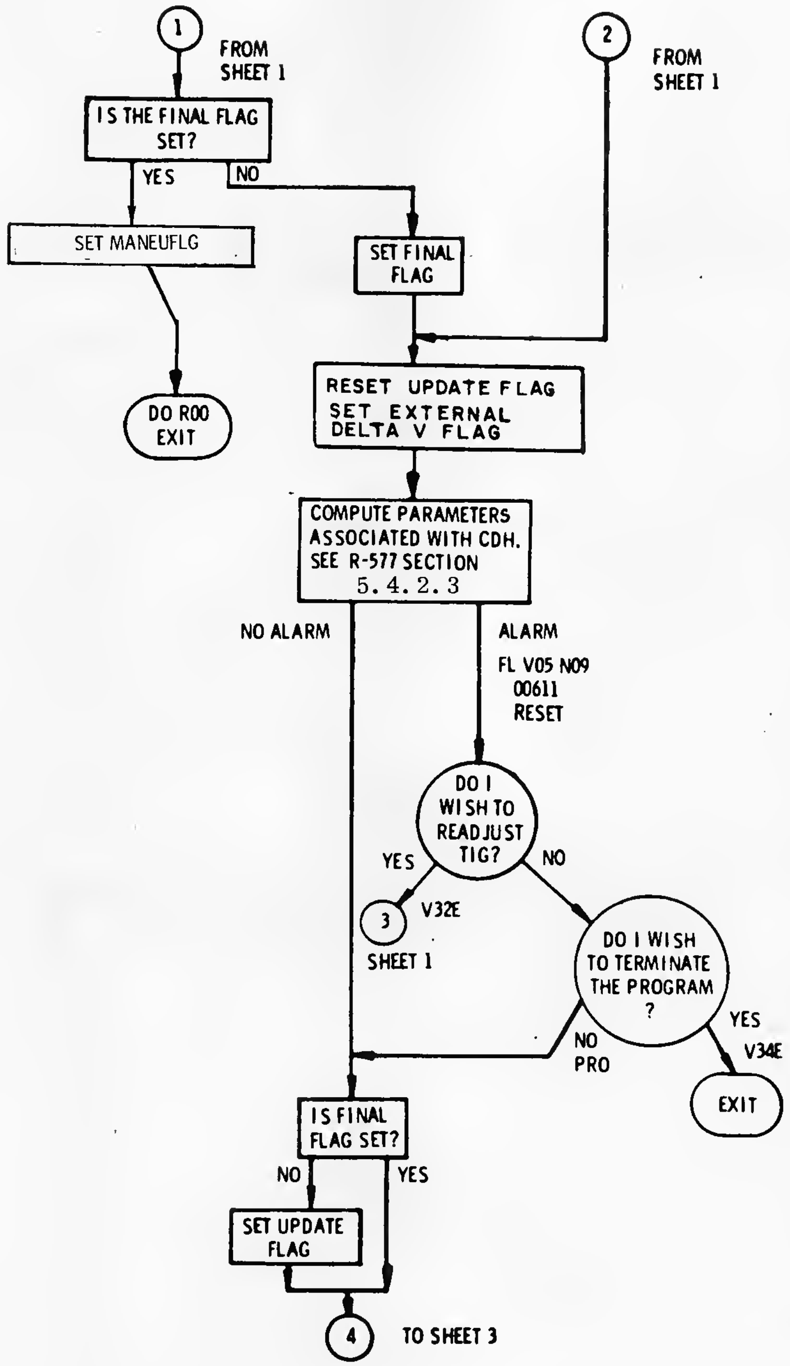
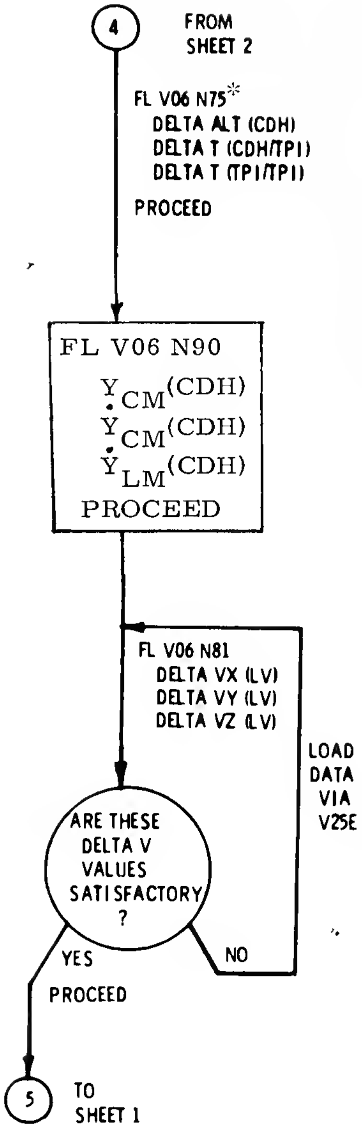


Figure 5.2.3-1. Constant Delta Altitude (CDH) Program (CSM P33) (Sheet 2 of 3)



NOTE: GETI (TPI) AVAILABLE VIA N37.

*Not displayed during MINKEY

Figure 5.2.3-1. Constant Delta Altitude (CDH) Program (CSM P33) (Sheet 3 of 3)

TABLE 5.2.3-I

P33 (CSM) INPUT

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1*	Time of CDH ignition	t_{IG}(CDH)	FL V06 N13	R1 ooxxx. hr R2 oooxx. min R3 oxx.xx sec	This time is initially computed by P32. It should be changed if LM did CSI, to LGC-computed t_{IG} (CDH) or to recover from alarm conditions. (See paragraph 5.2.3.4.)
2*	Time of TPI ignition	t_{IG}(TPI)	None	None	This time is also an input to P32. It is used as an initial guess in the pre-TPI routine called by P33 to calculate the actual time when E (input 3) exists. Under certain conditions, it may be changed to help recover from alarm conditions. To call it up, key in VERB 06 NOUN 37 ENTR. (See paragraph 5.2.3.4.)
3*	Elevation angle	E	None	None	This angle is also an input to P32. It will be displayed in R2 of NOUN 55 if it is called up by the astronaut. It can be changed to recover from alarm conditions. (See paragraph 5.2.3.4.)

* These inputs are already available in the CMC at the time P33 is keyed in if P32 has been completed prior to P33.

TABLE 5.2.3-II

P33 (CSM) OUTPUT (SHEET 1 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1	Accumulated marks	Mark counters	FL V16 N45	R1 xxBxx VHF marks, optics marks	VERB 32 ENTR starts computation process using latest update of state vector. PRO terminate mark process and completes final computation.
2	Time from ignition	TFI	FL V16 N45	R2 xxBxx min,sec max.= 59:59	Indicates time available for rendezvous navigation before CDH burn.
3	Middle gimbal angle	MGA	FL V16 N45	R3 xxx.xx deg	-00001 indicates a PRO response to VERB 16 NOUN 45 has not been received. -00002 indicates a PRO response has been received, and the alignment of the ISS is unknown. +xxx.xx indicates a PRO response has been received and shows the (positive) MGA at t_{IG}(CDH), in 0.01 degrees. A PRO response for a second time will allow the program to go to Routine 00 (terminate).
4**	Passive vehicle orbit altitude minus active vehicle orbit altitude at t_{IG}(CDH)	DELTA ALT(CDH)	FL V06 N75	R1 xxxx.x n. mi.	Normal response to VERB 06 NOUN 75 is PRO.

TABLE 5.2.3-II

P33 (CSM) OUTPUT (SHEET 2 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
5**	t_{IG}(TPI), as defined by P33, minus t_{IG} (CDH).	DELTA T(CDH/TPI)	FL V06 N75	R2 xxBxx: min, sec maximum: 59 min 59 sec	Display limited to 59:59 if negative Computed in hours, minutes, and seconds, of which only the minutes and seconds are displayed. (See expanded notes, below.) It is conceivable that this value might be negative; i.e., t_{IG} (TPI), as defined by P33, is before t_{IG} (CDH).
6**	t_{IG}(TPI), as defined by P33, minus t_{IG} (TPI), as defined by P32, earlier.	DELTA T(TPI/TPI)	FL V06 N75	R3 xxBxx: min, sec maximum: 59 min 59 sec	If a PRO response was received to alarm display VERB 05 NOUN 09, R3 will be zero, and R2 will be calculated using t_{IG} (TPI) as defined by P32.
7	Y_{CSM} out-of-plane position at T_{IG}(CDH)	Y_{CSM}	FL V06 N90	R1 xxx.xx n.mi.	
8	$\dot{Y}_{CSM}$ out-of-plane velocity at T_{IG}(CDH)	$\dot{Y}_{CSM}$	FL V06 N90	R2 xxx.x fps	$-\dot{Y}_{CSM}$ is the ΔVY(LV) component of N81.
9	$\dot{Y}_{LM}$ out=of-plane velocity at T_{IG}(CDH)	$\dot{Y}_{LM}$	FL V06 N90	R3 xxxx.x fps	
10	Impulsive v, in local vertical coordinates, for CDH	DELTA V(LV)		R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	Crew has the option at this time to redefine the $\Delta\underline{V}$(LV) components for the subsequent thrusting maneuver.

*t_{IG}(TPI) computed by P33 can be displayed by keying in VERB 06 NOUN 37 ENTR.

**Not displayed during MINKEY, but available by keying NOUN 75 ENTR at the FL VERB 16 NOUN 45 display at the end of computation cycle.

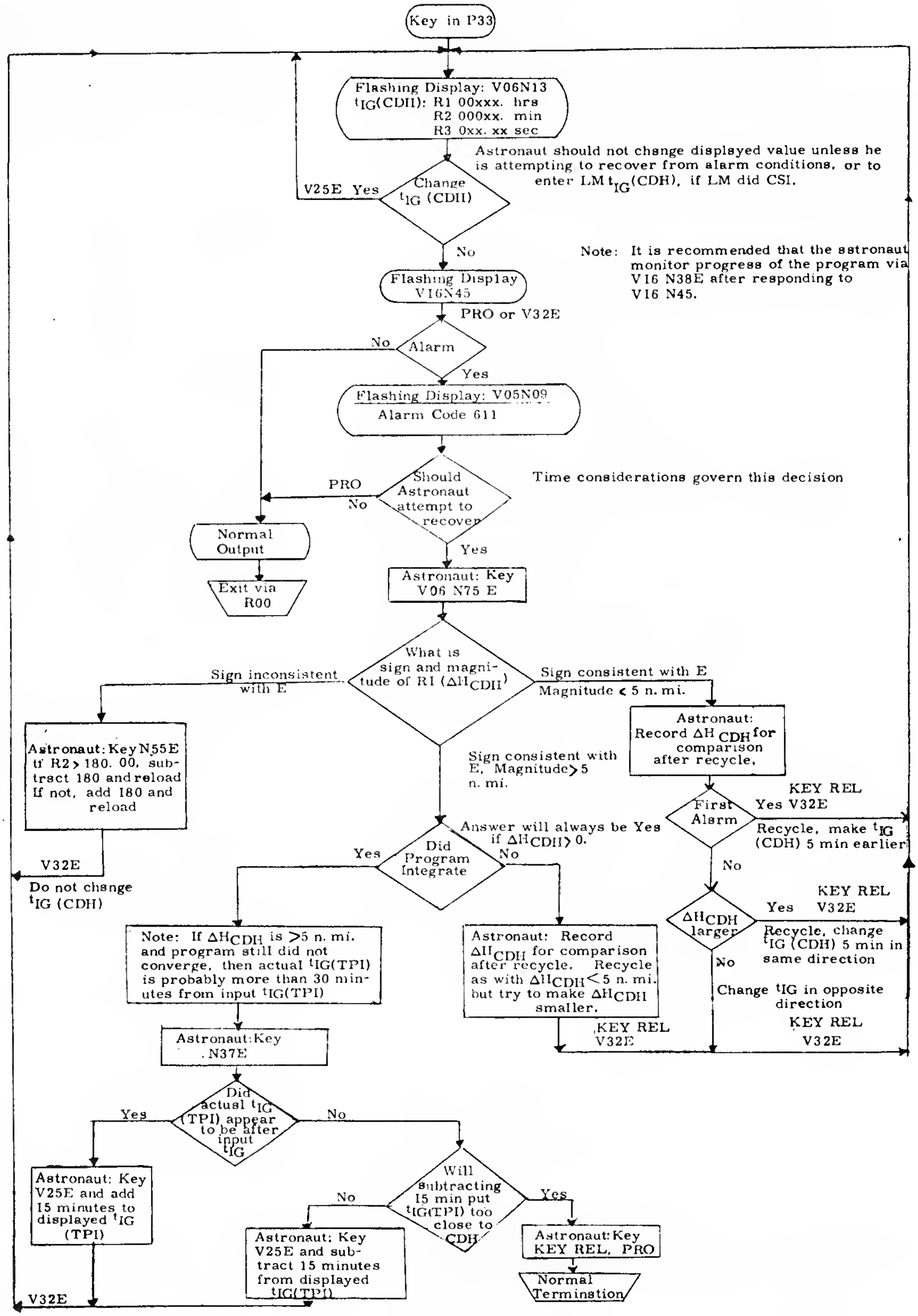


Figure 5. 2. 3-2. Alarm Code 00611 Conditions and Crew Actions

TABLE 5.2.3-III
P33 (CSM) ALARM RECOVERY SUMMARY

Circumstances giving rise to 00611 alarm	Diagnostic	Cause	Recovery
1. Excessive iterations	Monitor program via VERB 16 NOUN 38 ENTR. Oscillation occurs quickly. ΔH_{CDH} (R1 in NOUN 75) < 5 n. mi.	Pre CSI configuration slightly off-nominal; Not serious.	Record ΔH_{CDH} for comparison if alarm recurs. Attempt to increase magnitude of ΔH_{CDH}. Recycle, changing t_{IG}(CDH) by 5 min. intervals, according to change in ΔH_{CDH}
2. Excessive iterations	Monitor program via VERB 16 NOUN 38 ENTR. Actual t_{IG} appears far from input t_{IG}(TPI). Oscillation does not occur quickly. ΔH_{CDH} not necessarily small.	Post-CSI rendezvous navigation has produced significant changes in state vector estimates.	If time permits, change t_{IG}(TPI) via VERB 06 NOUN 37 ENTR, followed by appropriate load verb.
3. SIGN of ΔH_{CDH} inconsistent with E.	R1 NOUN 75 has wrong sign. (If E > 180°, ΔH_{CDH} must be negative. If E < 180°, ΔH_{CDH} must be positive).	Pre-CSI configuration is off-nominal, or wrong E was loaded.	Key in VERB 06 NOUN 55 ENTR; if E in R2 is less than 180°, add 180° and reload. If R2 is greater than 180°, subtract 180° and reload.
4. Active vehicle too high relative to passive vehicle.	R1 in NOUN 75 is negative and quite large.	Post-CSI navigation produced significant changes in state vector estimates.	Recycle as in 1, but attempt to diminish magnitude of ΔH_{CDH}

5.2.4 P34, Transfer-phase Initiation (TPI)—CMC

P34 targets for the Transfer Phase Initiation maneuver (TPI), a part of the rendezvous sequence. In the nominal trajectory, TPI initiates the direct rendezvous sequence (P34-P35). When used with the concentric flight plan (see subsections 5.1 and 5.2). P34 follows the coelliptic sequence (CSI-CDH), which produces coelliptic orbits and a particular elevation angle (E) between the active-to-passive LOS and the +x direction of the local-vertical coordinate frame. At t_{IG}(TPI), the second part of the rendezvous sequence,the transfer phase,begins,with the following characteristics:

a. The closing rate is slow
b. The changes in the LOS elevation angle are predictable
c. The direction of the thrust vector for the TPI maneuver very nearly coincodes with the LOS
d. The magnitude of the change in velocity, measured in feet per second, is very close to twice the difference in altitude between the orbits, measured in n. mi.

These characteristics allow for easy monitoring of the transfer phase and easy astronaut takeover in the event of computer malfunction during and after the TPI maneuver.

As with other rendezvous-targeting programs, P34 operates with option 0 or 4 of the Universal Tracking and Rendezvous Navigation Program (P20) in the background and targets a maneuver to be performed by the appropriate (P40/P41) powered-flight program. During the execution of P34, the crew can request preliminary targeting solutions which will temporarily interrupt the incorporation navigation measurements. The incorporation of navigation measurements cease, however, upon the crew's request for a final targeting solution.

P34 consists of two computation phases: the first sets up the input to the second. The first phase can be done one of two ways: it either accepts a desired E-angle and iterates to find the time when the angle exists, or it accepts a time and calculates the E-angle existing at that time.

The second phase takes the calculated (or requested) E-angle and calculated (or requested) time, and the requested CENTANG, and calculates a Lambert maneuver designed to effect intercept. The maneuver calculation can be done in one of two ways. The target vector is determined either conically, or with a specified number of precision offsets. (See Introduction to AGC Targeting—subsection 5.1—for a discussion of targeting trajectories and computations.)

5.2.4.1 P34 Computational Sequence

When P34 is called, it first enables tracking and mark incorporation by setting TRACK and UPDATE flags. Then the CMC flashes VERB 06 NOUN 37, which requests the astronaut to supply a t_{IG}(TPI) for the program. In the concentric flight plan, the time displayed will be that computed by P33. If a 00611 alarm out of P33 was bypassed, then the time displayed will be that input by the astronaut to P32 (unless it was subsequently changed by the astronaut). VERB 06 NOUN 55 is then displayed. NOUN 55 allows the astronaut to exercise the two choices available in P34: the E-angle-time (in R2, E does not equal 0 or E equals 0) choice, and the conic-precision offset targeting (in R1, NN equals 0 or NN does not equal 0) choice. After VERB 06 NOUN 55, P34 flashes VERB 16 NOUN 45, which allows the astronaut to monitor the progress of Rendezvous Navigation by displaying the mark counters. VERB 16 NOUN 45 also requests the astronaut to determine whether the next cycle will be a preliminary or a final computation. The appropriate responses are, VERB 32 ENTR and PRO, respectively.

After a response to VERB 16 NOUN 45 is made, the CMC prohibits further mark incorporation for the duration of the succeeding calculations by resetting the UPDATE flag. These calculations can be divided into two parts. If the E-option, or t_{IG}-computed option, is exercised, by loading + xxx.xx (where xxx.xx is nonzero) into R2, the first part of P34 is the pre-TPI routine, which determines exactly when the correct E-angle exists. If the proper time is found, then P34 flashes VERB 06 NOUN 37. If P34 cannot find the proper time, alarm 00611 occurs as a part of VERB 05 NOUN 09. If the time option, or E-computed option, is exercised, by loading +00000 in R2 of NOUN 55, the first part of P34 will take the input t_{IG}(TPI) and compute the E-angle existing at that time and flash the result as part of the VERB 06 NOUN 55 display.

> NOTE.—If the t_{IG}-computed option is selected during MINKEY rendezvous, the final computation computes t_{IG}(TPI) and then allows the crew to overwrite this value with the LM-computed t_{IG}(TPI)—LM active—or to PRO on the computed t_{IG}—CSM active. In either instance, an E-computed solution follows. (See Table 4.2.1-IV in the MINKEY Rendezvous section.)

After either E or the proper t_{IG}(TPI) is calculated and displayed, P34 targets an intercept course. The impulsive $\Delta \underline{v}$ is displayed in local vertical coordinates (VERB 06 NOUN 81), which can be overwritten by the crew. Also, when FL VERB 16 NOUN 45 occurs, the crew can key NOUN 59 ENTR and observe Δv computed in LOS coordinates. If the last computation was preliminary, the crew will probably wait until a few more marks are incorporated before requesting a final

computation. If the last computation was final, keying PRO in response to FL VERB 16 NOUN 45 allows P34 to exit via R00.

5.2.4.2 Inputs and Outputs

Figure 5.2.4-1 and Tables 5.2.4-I and 5.2.4-II present P34 sequencing and procedures. The following definitions apply:

1. TRACK and UPDATE flags refer to rendezvous navigation (P20 Options 0 or 4). If the TRACK flag is set, tracking is allowed. If the TRACK flag is reset, tracking is not allowed. If the UPDATE flag is set, marks will be incorporated; if it is reset, marks can be taken, but will not be incorporated.
2. FINAL flag set means a PRO response to a flashing VERB 16 NOUN 45 display has been received; reset, a PRO response has not been received.

Input 1, t_{IG}(TPI), will ordinarily be retained as displayed, if P33 was run before P34, since the P33-computed t_{IG}(TPI) should be quite close to the time when the actual elevation angle coincides with the desired E (input 3). If P34 is the first rendezvous-targeting program selected, however (i.e., for direct rendezvous), the t_{IG}(TPI) must be loaded by the crew.

Input 2, NN, governs which method of calculation the program will use in the second computation phase. If NN equals 00000, the program will calculate a conic approximation of the correct TPI maneuver. In the lunar gravitational sphere, the accuracy of this method is equivalent to target offsetting. Its advantage over the other method, called when NN does not equal 00000, is its speed in obtaining an answer.

Input 3, E governs which method of calculation the program will use in the first computation phase. If E equals 00000, the program will calculate a maneuver appropriate to the input t_{IG}(TPI). If E does not equal 00000, the program will accept the input number as an angle, to the nearest 0.01 degree, and use the input t_{IG}(TPI) (input 1) as an initial estimate for the pre-TPI routine.

Input 4, CENTANG, indicates the orbital central angle through which the passive vehicle must pass between t_{IG}(TPI) and intercept. Implicit in CENTANG is a target vector and a transfer time, which the Lambert targeting routine uses as input.

Table 5.2.4-II lists P34 output. VERB 16 NOUN 45 shows the status of rendezvous navigation (P20 Option 0 or 4): R1 shows the number of marks incorporated since the last W-matrix reinitialization; R2 shows how much time is left to take marks and perform the final P34 computation before ignition; R3 indicates whether the CMC will accept marks. If R3 equals -00001, then final computations have not been made by the CMC, and marks can be incorporated during some flashing displays. If the astronaut wishes to terminate the marking process and use the current estimate of the state vectors in the CMC for a final P34 solution, he should key PRO in response to a VERB 16 NOUN 45 display. After PRO, no more marks will be incorporated in the CMC state vector. The computer will calculate the maneuver parameters for a final time, display the various other outputs, and then redisplay VERB 16 NOUN 45. After a final computation, the IMU status is indicated in R3. If alignment is unknown, R3 equals -00002. Otherwise, the middle gimbal angle (contents of R3) at t_{IG}(TPI) will be shown as a positive number. A second PRO response to VERB 16 NOUN 45* will terminate the program via Routine 00. (A VERB 32 ENTR response at this point is undesirable because no parameters will change—that is, no marks will be accepted or incorporated.)

Depending on the mode used, either a VERB 06 NOUN 55 or a VERB 06 NOUN 37 will flash after all but the final VERB 16 NOUN 45 displays. If the time option (E equals 00000) was exercised, the program will compute E for the specified t_{IG}(TPI), and display it as R2 (output 5) in a VERB 06 NOUN 55 display. Registers 1 and 3 will be identical with inputs 2 and 4, supplied by the astronaut. If the E option is exercised, output 7, the computed t_{IG}(TPI), will be flashed in a VERB 06 NOUN 37 display.

After either the NOUN 55 or the NOUN 37 display, the program calculates the $\Delta \underline{v}$ required for the TPI maneuver (see Figure 5.2.4-1). When the thrust vector is calculated, the program flashes a VERB 06 NOUN 58 display, containing outputs 8, 9 and 10 in R1, R2 and R3, respectively. Refer to Table 5.2.4-II for an explanation of these outputs, which represent the magnitudes of the initial and final maneuvers of the transfer phase. Output 11 shows the thrust vector displayed in the local-vertical coordinates at t_{IG}(TPI). The velocity vector is also computed in LOS coordinates, which can be viewed by the crew's keying NOUN 59 ENTR upon the flashing VERB 16 NOUN 45 display. (For a description of the local-vertical coordinate system, refer to paragraph 5.1.5.) The LOS coordinate system can be described as follows:

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* If MINKEY is active W-Matrix reinitialization values are changed automatically to 2000 ft, and 2 ft/sec.

LOS Coordinate System

$$\underline{X}\ (LOS) = \text{unit}\ (\underline{r}_P - \underline{r}_A)$$

$$\underline{Y}\ (LOS) = \text{unit}\ \left[((\underline{r}_A \times \underline{v}_A) \times \underline{X}\ (LOS)) \times \underline{X}\ (LOS)\right]$$

$$\underline{Z}\ (LOS) = \text{unit}\ \left[\underline{X}\ (LOS) \times \underline{Y}\ (LOS)\right]$$

In other words, the active-passive LOS is along the +X(LOS) axis. $\underline{Y}$(LOS) is perpendicular to $\underline{X}$(LOS), in the plane formed by $\underline{X}$(LOS) and $\underline{Y}$(LV). $\underline{Z}$(LOS) completes the right-handed system.

As was mentioned above, VERB 16 NOUN 45 is flashed after final computation, before the program terminates, and R3 equals either -00002 or the positive middle gimbal angle at t_{IG}(TPI).

5.2.4.3 Program Coordination

As in other rendezvous-targeting programs, P34 operates with P20 Option 0 or 4 in the background. Although P20 requires that the ISS be running and aligned, P34 does not. Optics marks can be taken during any P34 flashing display; VHF marks can accumulate throughout the program. Marks are only incorporated, however, during the initial NOUN 55 and NOUN 37 displays and during the NOUN 45 and NOUN 81 displays preceding the request for final computation (PRO to flashing VERB 16 NOUN 45). The P34 targeting solution is used by the appropriate powered-flight program (P40/P41) to perform the maneuver. (Rendezvous sequencing is described in paragraphs 4.2.1.2.2—Manual—and 4.2.1.2.6—MINKEY.)

5.2.4.4 Program Limitations

Under certain conditions, such as a small ΔH_{CDH}, the program may not be able to find the desired E-angle. This will cause a 00611 alarm code to be flashed as part of a VERB 05 NOUN 09 display. If the desired E-angle cannot be found, the procedures outlined in paragraph 5.2.4.5 should be followed. The time option will always produce a solution for rendezvous.

5.2.4.5 Alarms

Alarm 00611 is the only alarm code likely to occur during P34. The circumstances under which alarm 00611 might occur are described in paragraph 5.2.3.4. Unless CDH is poorly performed, this alarm should occur during P33 when the CM pilot is likely to have more time to search for a solution. In a time-critical situation like

the period between CDH and TPI, the iteration process used to find t_{IG}(TPI) is usually too lengthy to be used more than once. Therefore, if a 00611 alarm should occur in P34, it is recommended that the CM pilot recycle (by keying in VERB 32 ENTR) use the time option (input 3, E equals 00000) and leave the other inputs unchanged.

5.2.4.6 Restarts

P34 is protected against restarts. If one should occur during P34 operation, no loss of accuracy, but a loss of time—equal at most to the time required for a final computation—would occur.

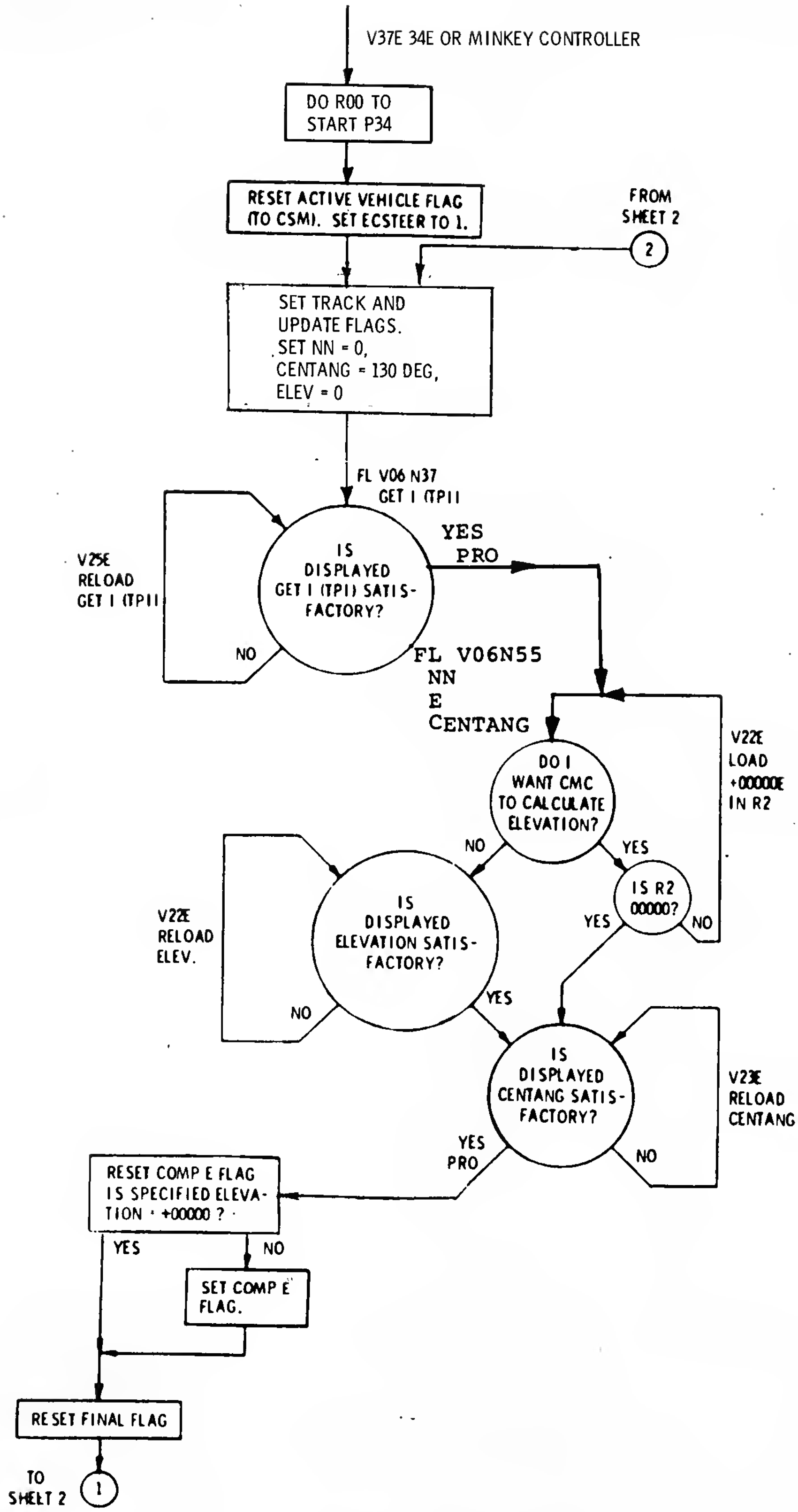


Figure 5.2.4-1. Transfer-phase Initiation Program (CSM P34) (Sheet 1 of 3)

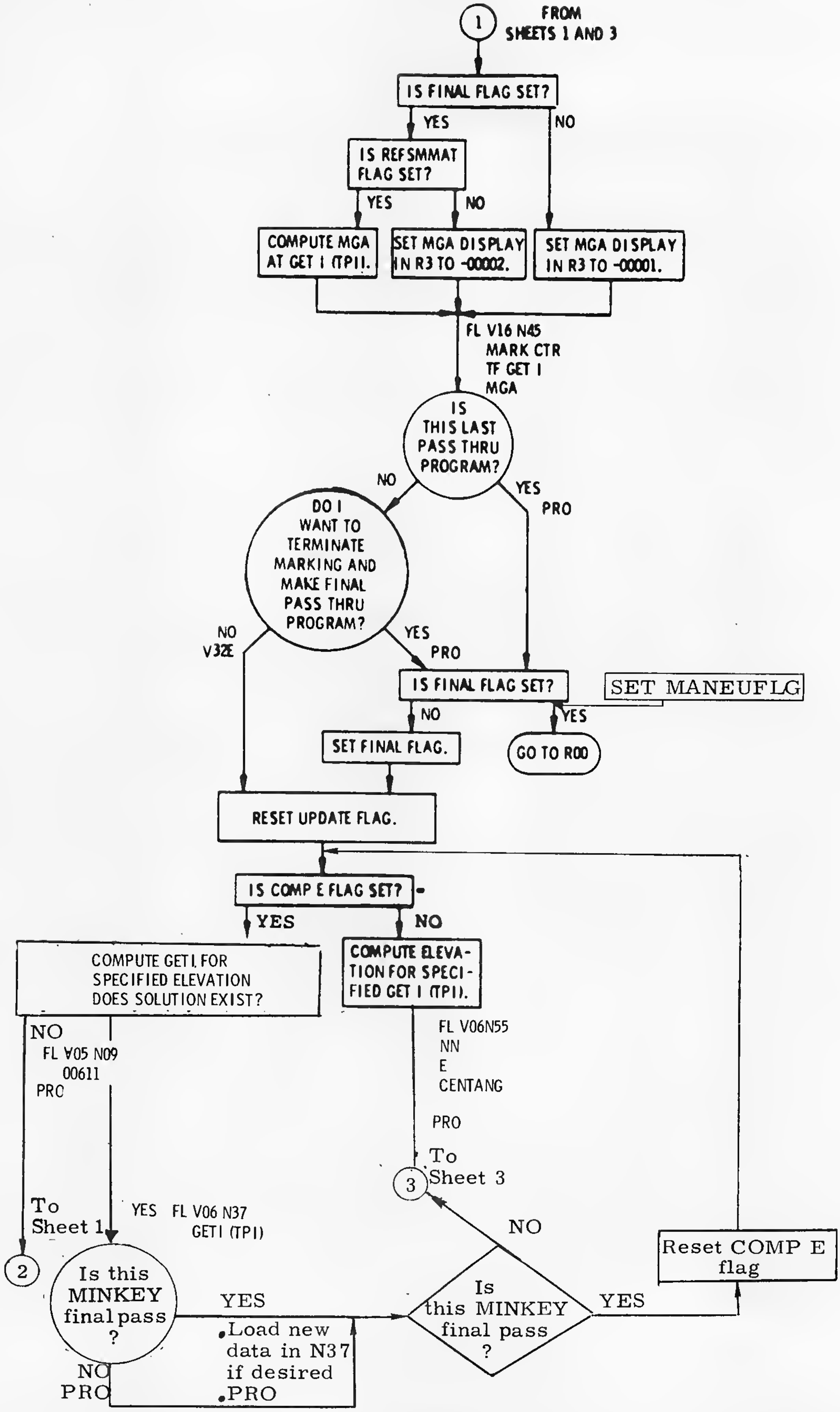


Figure 5.2.4-1. Transfer-phase Initiation Program (CSM P34) (Sheet 2 of 3)

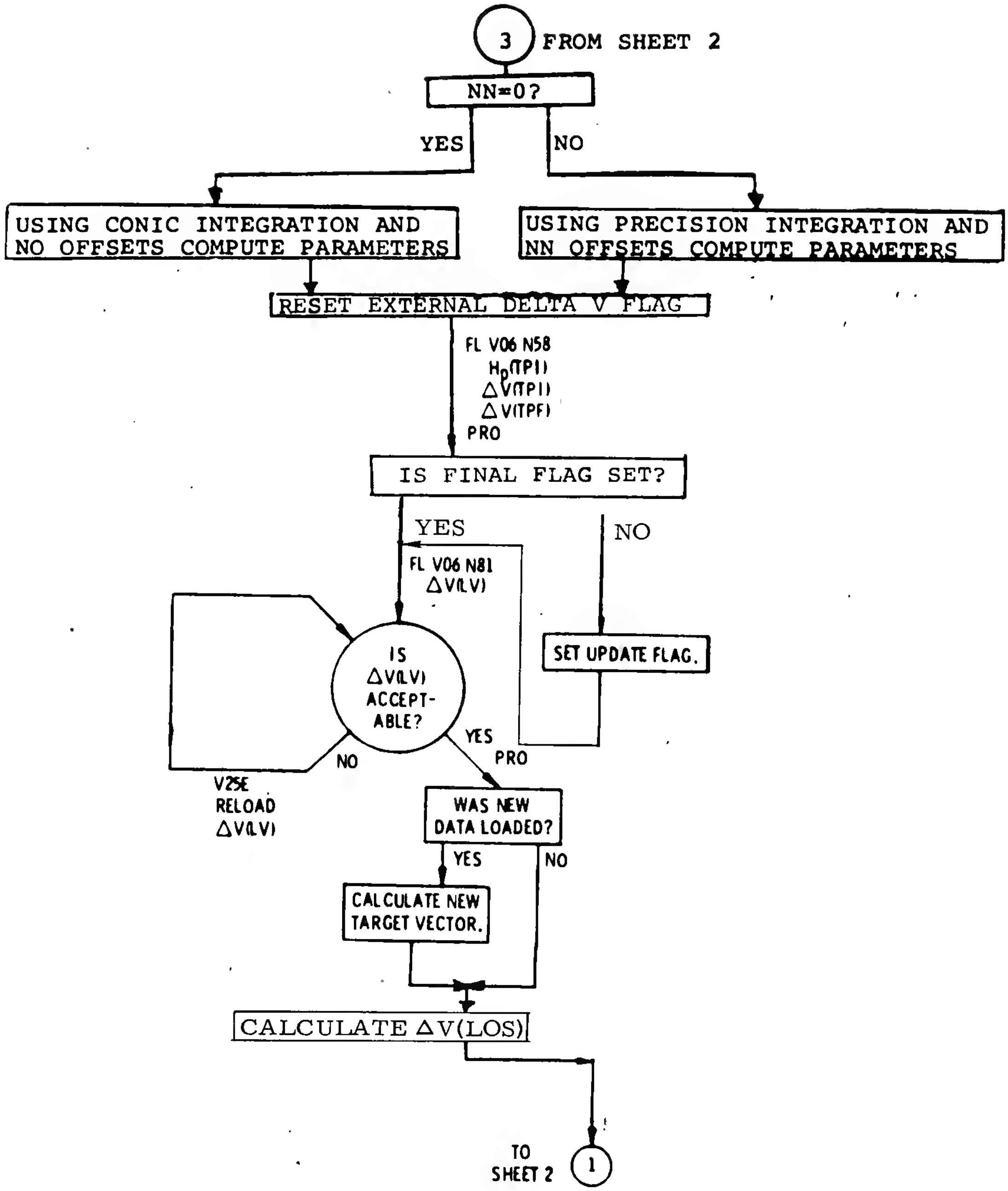


Figure 5.2.4-1. Transfer-phase Initiation Program (CSM P34) (Sheet 3 of 3)

TABLE 5.2.4-I

P34 (CSM) INPUTS

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1	TPI time of ignition	TIG(TPI)	FL V06 N37	R1 00xxx. hr R2 000xx. min R3 0xx.xx sec	This will initially display the value computed by P33 if P33 was run prior to P34 (unless subsequently changed by the astronaut). If the E-option is used, input 1 will be used as an initial guess as the program tries to locate the time when the elevation angle coincides with the desired E(input 3). If the time option is exercised, then input 1 will be the actual t_{IG}(TPI).
2	Conic-precision switch; if positive, number of offsets to be used in Lambert targeting.	NN	FL V06 N55	R1 00000 Unless changed by astronaut	If input 2 = 00000, the recommended value for lunar orbital activities, the very fast conic integration will be used to calculate the TPI maneuver. Input 2 = +00002 is recommended for earth orbit activities to account for oblateness effects. Any positive number will cause the program to use precision offsets.
3	E-option-time-option switch; if nonzero, desired E angle	E	FL V06 N55	R2 000.00 deg Unless changed by astronaut	If input 3 = 00000, program will accept input 1 as desired t_{IG}(TPI), and calculate a TPI maneuver for that time. If input 3 $\neq$ 00000, the program will use input 1 as an initial guess in an attempt to find the time when the elevation angle coincides with input 3.
4	Central angle through which the passive vehicle must pass from t_{IG}(TPI) to intercept.	CENTANG	FL V06 N55	R3 130.00 deg Unless changed by astronaut	This is set according to mission procedures.

TABLE 5.2.4-II

P34 (CSM) OUTPUTS (SHEET 1 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1	Accumulated Marks	Mark Counters	FL V16 N45	R1 xxBxx VHF marks, optics marks	VERB 32 ENTR starts computation process using latest update of state vectors. A PRO terminates mark incorporation and completes final computation.
2	Time from Ignition	TFI	FL V16 N45	R2 xxBxx min, sec maximum: 59 min, 59 sec	Indicates time available for rendezvous navigation before TPI burn.
3	Middle Gimbal Angle	MGA	FL V16 N45	R3 xxx.xx deg	-00001 indicates a PRO response to VERB 16 NOUN 45 has not been received. -00002 indicates a PRO response has been received, and the alignment of the ISS is unknown. +xxx.xx indicates a PRO response has been received and shows the (positive) MGA at t_{IG}(TPI), in 0.01 degrees. A PRO response for a second time will allow the program to go Routine 00.
	If the astronaut requested the time option by putting in +00000 for E (input 3), then outputs 4, 5 and 6 will follow outputs 1, 2 and 3, and then output 8 will follow. Otherwise 4, 5, and 6 will be skipped, and 7 will follow 1, 2, and 3.				NOTE. For MINKEY final pass, outputs 4, 5, and 6 follow output 7. (See MINKEY Table 4.2.1-IV.)
4	Number of target offsets	NN	FL V06 N55	R1 xxxxx	This register will display whatever was put in by the astronaut.
5	Elevation angle. (see input 3 for definition)	E	FL V06 N55	R2 xxx.xx deg	This register will now display the actual elevation angle for the given t_{IG}(TPI).

TABLE 5.2.4-II

P34 (CSM) OUTPUTS (SHEET 2 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
6	Orbital central angle of the passive vehicle during transfer from t_{IG}(TPI) to intercept.	CENTANG	FL V06 N55	R3 xxx.xx deg	This register will display whatever was put in by the astronaut.
7	Calculated time of ignition for TPI	TIG(TPI)	FL V06 N37	R1 ooxxx. hrs R2 oooxx. min R3 oxx.xx sec	When the astronaut wishes to do TPI with a certain E-angle, the program searches for a time when that E-angle exists. Output 7 is that time.*
8	Perigee altitude	PER ALT	FL V06 N58	R1 xxxx.x n.mi.	This perigee altitude is altitude above pad radius, for the earth, or altitude above the latest landing site, for the moon.
9	Impulsive change in velocity for TPI	ΔV(TPI)	FL V06 N58	R2 xxxx.x fps	P34 and P35 burns are Lambert maneuvers.
10	Impulsive change in velocity for TPF	ΔV(TPF)	FL V06 N58	R3 xxxx.x fps	
11**	Impulsive change in velocity vector in local vertical coordinates	ΔV (LV)	FL V06 N81	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	Crew has the option at this time to redefine the Δv (LV) components for the subsequent thrusting maneuver.

*If this is MINKEY, see rendezvous procedures in paragraph 4.2.1.2.6. This noun can be loaded with the LM-computed TIG(TPI).

**The impulsive change in velocity vector in line-of-sight coordinates ΔV (LOS) is available by keying NOUN 59 ENTR at the FL VERB 16 NOUN 45 at the completion of the computation cycle.

5.2.5 P35, Transfer-phase Midcourse (TPM)—CMC

P35 targets a midcourse correction for the transfer phase of the rendezvous sequence. All of the P35 inputs are available in the computer at the time it is selected; the astronaut need not key in anything but P35, itself. The inputs to P35 are as follows:

a. Active and passive vehicle state vectors, as updated by P20 (Options 0 or 4)

b. Time of intercept, as calculated by P34

c. Time of ignition, defined as follows:

   Current time + A, where current time is when a solution is requested (final or preliminary) and where A is pad-loaded, crew-loaded, or loaded via P27. (Current nominal value of A is 3 min.)

d. NN, the conic-precision offset target switch, input in P34 as R1 of NOUN 55.

> NOTE.—The effect of input c is to allow the crew to control the time of t_{IG} by controlling the instant a request is made for a solution. For example, if 15-minute intervals are desired between midcourse maneuvers, the crew waits until 12 minutes have elapsed since the preceding t_{IG}, requests a final solution (PRO to FL VERB 16 NOUN 45), and gets a solution for a t_{IG} 3 minutes after the PRO. Since any response to FL VERB 16 NOUN 45, whether a recycle or a request for final solution, defines a new t_{IG}, requests for preliminary solutions in P35 are pointless.

Given the above inputs, P35 targets a midcourse correction using the Lambert routine. It computes the required Lambert target vector and transfer time and displays the required impulsive $\Delta \underline{v}$ in local-vertical coordinates. The required impulsive $\Delta \underline{v}$ is also computed in LOS coordinates and can be viewed by the crew's keying NOUN 59 ENTR at a flashing VERB 16 NOUN 45 display.

As in the other rendezvous targeting programs, P35 operates with P20 Option 0 or 4 in the background and allows navigation marks to be incorporated (during any flashing display) up until the time the crew requests a final targeting computation. (See description of P20 Rendezvous Mode, paragraph 4.2.1.2.)

5.2.5.1 P35 Computational Sequence

The P35 computational flow is illustrated by Figure 5.2.5-1. Inputs and outputs are listed in Tables 5.2.5-I and 5.2.5-II respectively.

When P35 is selected, it first enables tracking and mark incorporation by setting TRACK and UPDATE flags. Then the CM computer flashes VERB 16 NOUN 45, the standard monitor for P20. The first time VERB 16 NOUN 45 comes up, the time from ignition (TFI, in R2) will be positive, indicating time since the preceding maneuver. Upon the crew's request for a final soultion, however, the sign of the value in R2 becomes negative, indicating time from the maneuver that is being targeted.

As described in the note above, a PRO response to FL VERB 16 NOUN 45 causes a pad-loaded or uplinked increment (A) to be added to the present time. Present time +A then becomes the t_{IG} for the upcoming maneuver. The CMC uses the time of intercept computed in P34 to extrapolate the target vector. If NN was nonzero in P34, indicating a certain number of precision offsets, P35 will use that number of precision offsets in computing the target vector. If NN was zero in P34, P35 will compute the target vector using conic integration.

After the target vector and corresponding $\Delta \underline{v}$ have been computed, P35 flashes the $\Delta \underline{v}$ in local-vertical coordinates via VERB 06 NOUN 81. The $\Delta \underline{v}$ is also computed in LOS coordinates and can be seen by keying NOUN 59 ENTR at a flashing VERB 16 NOUN 45 display.

The final display, common to all targeting routines, is VERB 16 NOUN 45. PRO allows P35 to exit via R00.*

5.2.5.2 Restrictions and Limitations

If input 4 (CENTANG) to P34 was greater than 180 deg, the transfer angle from position at t_{IG}(TPM) to the target vector (available from VERB 06 NOUN 52) might be in the range 165 to 195 deg. If it is, P35 will rotate the target vector into the plane of the active vehicle. This will result in the loss of any out-of-plane correction. If the transfer angle is in the range of 165 to 195 deg, it is recommended that the maneuver be recalculated about 12 minutes later in the lunar sphere, to eliminate the loss of any out-of-plane correction. A delay allows the transfer angle to become less than 165 deg.

5.2.5.3 Restarts

If a restart occurs during the calculation of the TPM maneuver (after a response to VERB 16 NOUN 45 but before the next display), P35 starts again just after the VERB 16 NOUN 45 display. Since A, the time increment (refer to 5.2.5 c), is added to the current time after the restart protection point in the program, the maneuver will be targeted for a time slightly later than A plus the time of restart occurrence.

*If MINKEY is active, W-Matrix reinitialization values are changed automatically to 2000 ft. and 2 ft./sec.

TABLE 5.2.5-I
P35 (CSM) INPUTS

Input	Identification	Input Source (no inputs are displayed)	Comments
1*	Time of midcourse correction	TIG (TPM) is the time when the current recycle or final computation was requested, plus an erasable-memory delay interval, A. A is usually about three minutes.	Given that t_{IG} (TPM) changes with each recycle or final computation (or restart, if one occurs between the request for a recycle or final computation and the corresponding solution), one can expect the calculated maneuver to change somewhat with each computation.
2*	Time of intercept	Calculated by P34 from CENTANG.	
3*	Conic-Precision offset target switch, NN.	If P34 was requested to do conic targeting (R1 of NOUN 55 = 00000), P35 will do the same. If P34 did a certain number of precision offsets, P35 will do the same number.	

*No actual input is required.

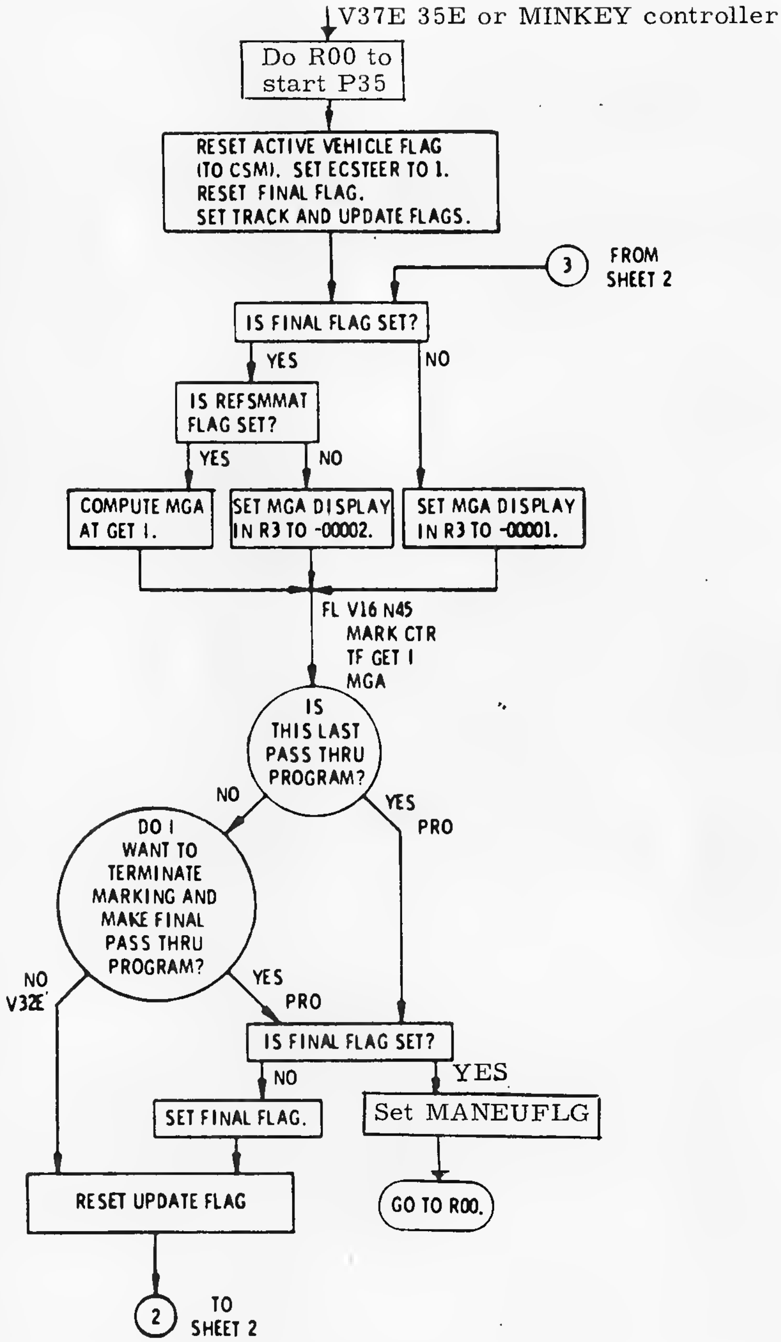


Figure 5.2.5-1. Transfer-phase Midcourse Program (CSM P35) (Sheet 1 of 2)

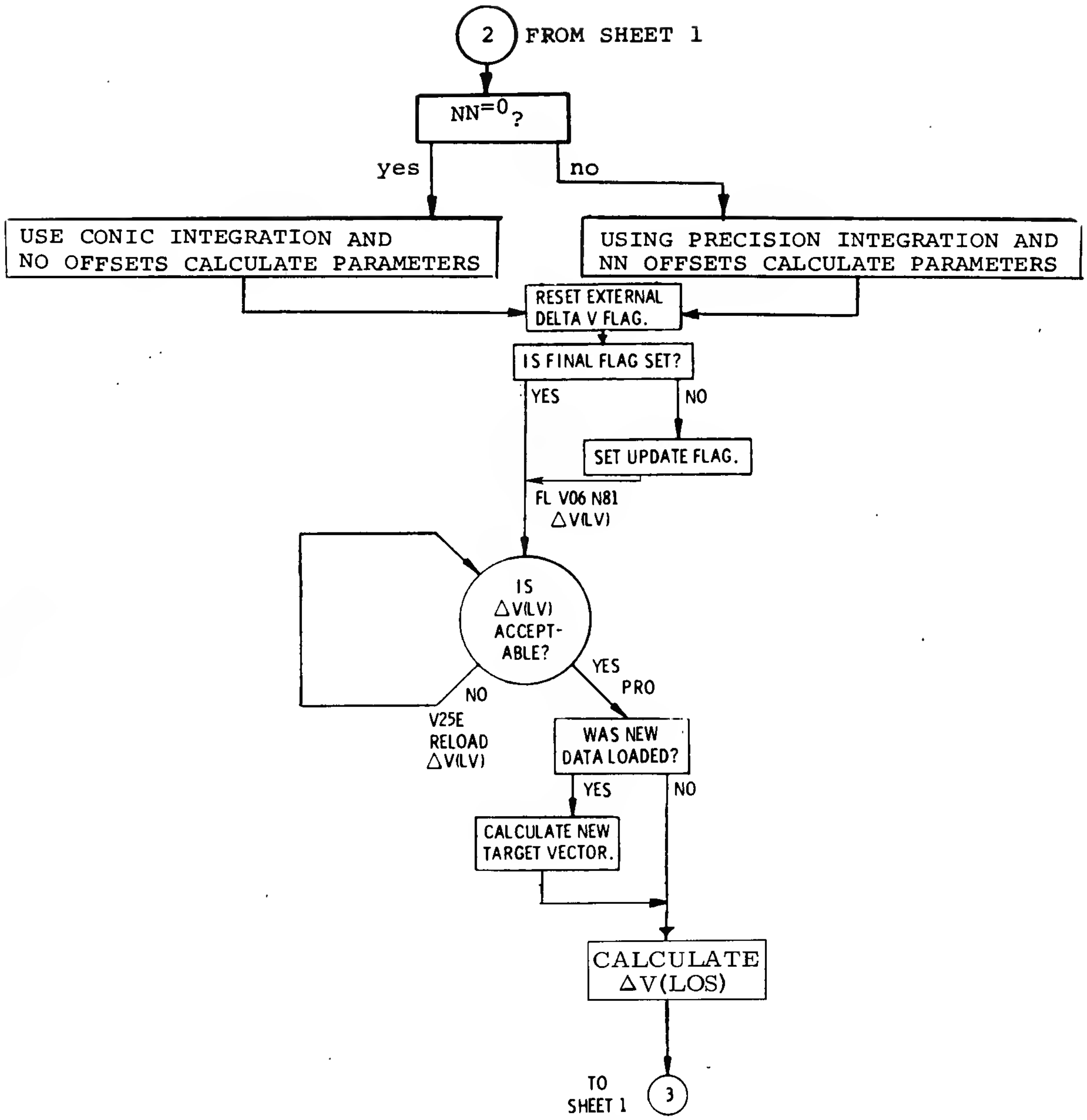


Figure 5.2.5-1. Transfer-phase Midcourse Program (CSM P35) (Sheet 2 of 2)

TABLE 5.2.5-II

P35 (CSM) OUTPUTS

Output	Identification	Mnemonic	DSKY	Register	Comments
1	VHF and optics marks incorporated since the W-matrix was reinitialized.	Mark counters	FL V16 N45	R1 xxBxx	A VERB 32 ENTR response to a flashing VERB 16 NOUN 45 display will recycle for a preliminary computation. An initial PRO response will halt incorporation of marks and allow final computation. If it is decided that the final computation cannot be used, a VERB 32 ENTR response will allow a final comp with a slightly later t_{IG}(TPM). Once an initial PRO has been keyed in response to a flashing VERB 16 NOUN 45 display, no more marks will be incorporated until UPDATE flag is once again set--for instance by reselecting P35.
2	Time from ignition	TFI	FL V16 N45	R2 xxBxx min, sec	
3	Final computation; recycle indicator. Middle gimbal angle at t_{IG}(TPM)	Middle gimbal angle	FL V16 N45	R3 xxx.xx deg	If displayed value = -00001, PRO has not been keyed in response to a VERB 16 NOUN 45 flashing display. If PRO has been keyed in response to that display, then a positive number indicates the MGA at t_{IG}(TPM). -00002 indicates IMU alignment is not currently known.
4*	Impulsive change in velocity, in Local Vertical Coordinates.	DELTA V(LV)	FL V06 N81	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	Crew has the option at this time to redefine the $\Delta\underline{v}$(LV) components for the subsequent thrusting maneuver.

*The impulsive change in velocity in Line-of-Sight coordinates Δv(LOS) is available by keying NOUN 59 ENTR at the FL VERB 16 NOUN 45 at the end of the computation cycle:

R1 xxxx.x fps X
R2 xxxx.x fps Y
R3 xxxx.x fps Z

5.2.6 P37, Return-to-earth—CMC

Program P37 provides the crew with an onboard means of targeting for a Lambert-aimpoint maneuver that will return the spacecraft to a proper earth-reentry state.* Targeting with P37 is wholly independent of earth communication and can be used either for an SPS maneuver (P40) or an RCS maneuver (P41).** The program can be utilized to return from (a) earth orbit, (b) trajectories resulting from translunar-injection powered-maneuver failure, (c) translunar coast (outside lunar sphere of influence), and (d) transearth coast, including midcourse corrections (again, outside lunar sphere of influence). (See Figures 5.2.6-1, -2, and -3.)

5.2.6.1 Options and Crew Inputs

P37 has three basic options—minimum fuel, minimum time, and adjusted landing site. For either of the three, the crew enters five inputs via the DSKY and receives fifteen outputs. (See Table 5.2.6-I, and refer to program flow, Figure 5.2.6-4.) The first six outputs present a relatively fast, conic-section solution; the second six (outputs 7—12) present the precision-solution equivalent of the first six, recomputed to consider gravitational perturbations. After keying in VERB 37 ENTR 37 ENTR, the crew enters the first three inputs as requested by the DSKY—desired ignition time (t_{IG}), desired velocity change (Δv_D), and desired reentry angle $[\gamma(t_2)_D]$. Whether it is to be a minimum-fuel or a minimum-time return is determined by the input Δv_D. Whether it is to be an adjusted-landing-site return is determined by crew decision to vary certain of the inputs in order to effect a desired change in landing-site longitude.

5.2.6.1.1 Minimum-fuel Option.—For a minimum-fuel return, the crew allows zero to remain in register 2 in response to the DSKY's flashing VERB 06 NOUN 60. A Δv_D of zero signals the program to compute a trajectory requiring the minimum possible velocity change. In addition, from certain earth-orbital conditions (see Figure 5.2.6-5), the crew can further minimize fuel consumption by selecting a shallower entry flight-path angle than would be otherwise automatically computed by the program. That is, in response to VERB 06 NOUN 60, the crew can leave a zero $\gamma(t_2)_D$ in R3, allowing the program to solve for a flight-path angle obtaining

*See Appropriate GSOP: Section 4, "GNCS Operational Modes," and Section 5 (paragraph 5.4.3), "Guidance Equations."

**See paragraph 5.2.6.8 for a special application of P37 outputs to returns using the lunar-module propulsion system.

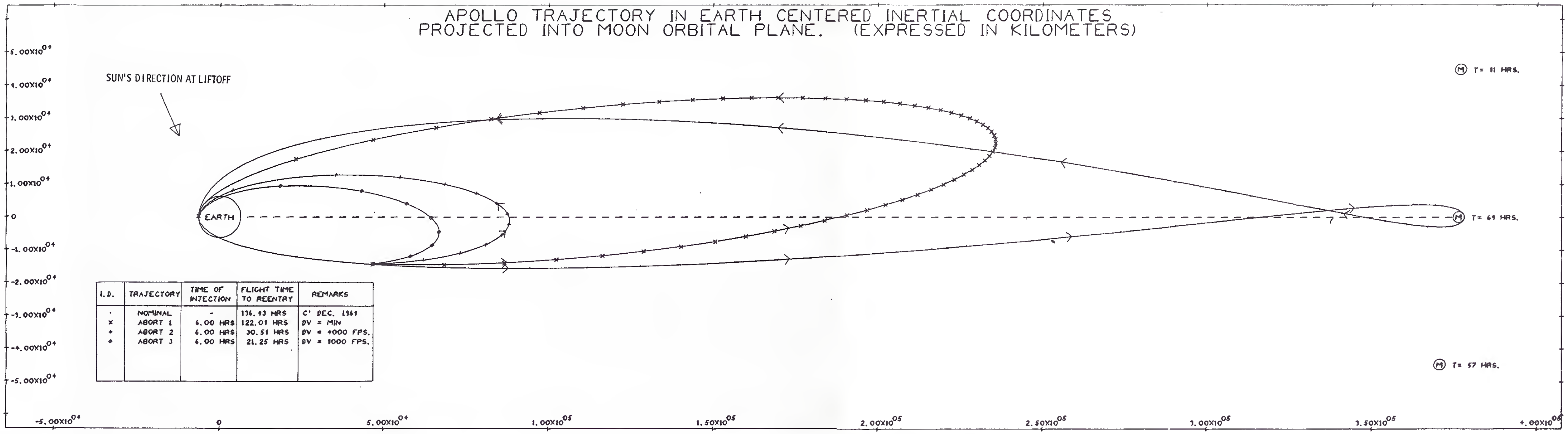
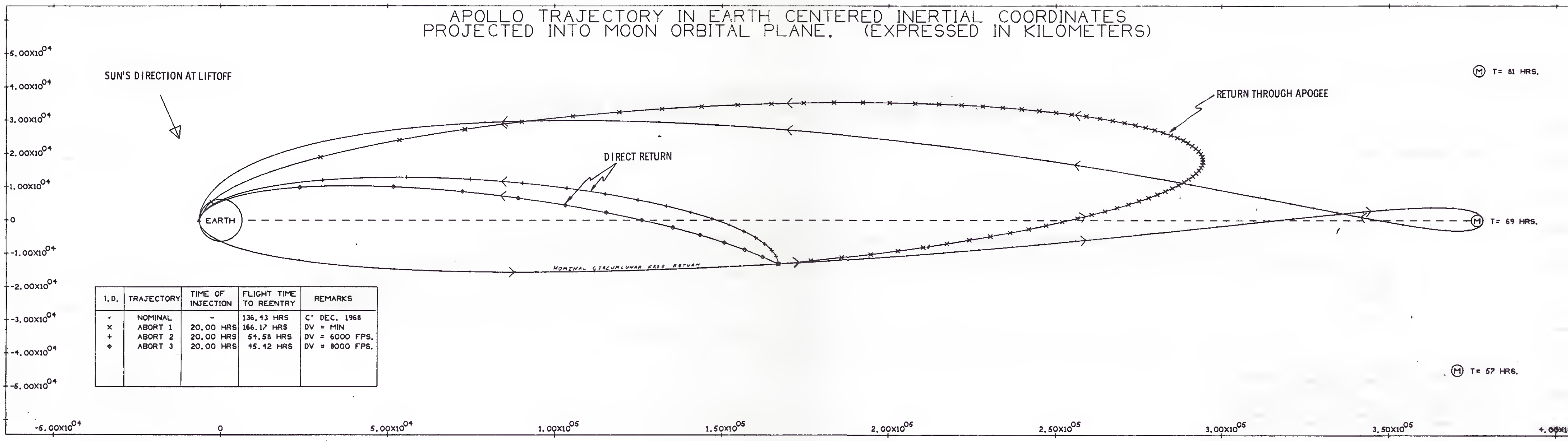
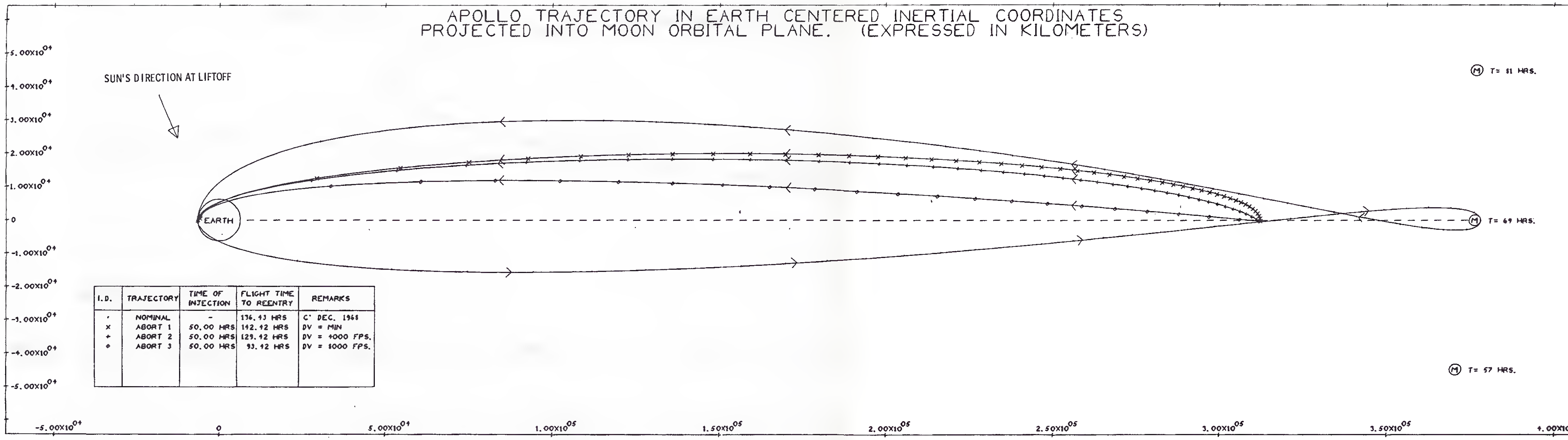

APOLLO TRAJECTORY IN EARTH CENTERED INERTIAL COORDINATES
PROJECTED INTO MOON ORBITAL PLANE. (EXPRESSED IN KILOMETERS)
SUN'S DIRECTION AT LIFTOFF
EARTH
M T= 11 HRS.
M T= 69 HRS.
M T= 57 HRS.
I.D. | TRAJECTORY | TIME OF INJECTION | FLIGHT TIME TO REENTRY | REMARKS
· | NOMINAL | - | 136.43 HRS | C' DEC. 1961
x | ABORT 1 | 6.00 HRS | 122.01 HRS | DV = MIN
+ | ABORT 2 | 6.00 HRS | 30.51 HRS | DV = 4000 FPS.
◆ | ABORT 3 | 6.00 HRS | 21.25 HRS | DV = 1000 FPS.
5.00X10^04
4.00X10^04
3.00X10^04
2.00X10^04
1.00X10^04
0
-1.00X10^04
-2.00X10^04
-3.00X10^04
-4.00X10^04
-5.00X10^04
-5.00X10^04
0
5.00X10^04
1.00X10^05
1.50X10^05
2.00X10^05
2.50X10^05
3.00X10^05
3.50X10^05
4.00X10^05

Figure 5.2.6-1.



I.D.	TRAJECTORY	TIME OF INJECTION	FLIGHT TIME TO REENTRY	REMARKS
⁃	NOMINAL	-	136.43 HRS	C' DEC. 1968
×	ABORT 1	20.00 HRS	166.17 HRS	DV = MIN
+	ABORT 2	20.00 HRS	54.58 HRS	DV = 6000 FPS.
◇	ABORT 3	20.00 HRS	45.42 HRS	DV = 8000 FPS.

Figure 5.2.6-2. Typical Abort Trajectories for TLI +20 Hours



I.D.	TRAJECTORY	TIME OF INJECTION	FLIGHT TIME TO REENTRY	REMARKS
·	NOMINAL	-	136.43 HRS	C' DEC. 1968
×	ABORT 1	50.00 HRS	142.42 HRS	DV = MIN
+	ABORT 2	50.00 HRS	129.42 HRS	DV = 4000 FPS.
◆	ABORT 3	50.00 HRS	93.42 HRS	DV = 8000 FPS.

Figure 5.2.6-3.

TABLE 5.2.6-I

P37 (CSM) CREW INPUTS AND PROGRAM OUTPUTS (SHEET 1 OF 2)

Input	Identification	Display Mnemonic	DSKY	Register
1.	Desired Ignition Time (t_{IG})	TIG (GET I)	FL V06 N33	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec
2.	Desired Velocity Change (Δv_D)	VPRED	FL V06 N60	R2 xxxxx. fps
3.	Desired Reentry Angle $[\gamma(t_2)_D]$	GAMMA EI	FL V06 N60	R3 xxx. xx deg*
4.	Vehicle Mass and Number of Jets **			
5.	Desired Propulsion System	SPS RCS	FL V04 N06	R2 00001 (R1 00007) R2 00002 (R1 00007)
Output				
1.	Landing-site Latitude (θ_{LAT})	IMPACT LAT	FL V06 N61	R1 xxx. xx deg*
2.	Landing-site Longitude (θ LONG)	IMPACT LONG	FL V06 N61	R2 xxx. xx deg*
3.	Time of Flight ($t_2 - t_1$, or t_{21})	DELTA T TRANS	FL V06 N39	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec
4.	Velocity at Entry $[v(t_2)]$	VPRED	FL V06 N60	R2 xxxxx. fps
5.	Entry Flight-path Angle $[\gamma(t_2)]$	GAMMA EI	FL V06 N60	R3 oxx. xx deg*
6.	Impulsive Velocity Change ($\Delta \underline{v}$)	DELTA V (LV)	FL V06 N81#	R1 (VX) xxxx. x fps*** R2 (VY) xxxx. x fps*** R3 (VZ) xxxx. x fps***
7-12.	Outputs 1-6 recomputed, giving precision solution			
13.	Ignition Time (t_{IG})	TIG (GET I)	FL V06 N33	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec

the center of the entry corridor; or by keying into R3 a specified entry angle, the crew can request the program to solve for a shallower $\gamma(t_2)$, requiring less fuel. For example, observe in Figure 5.2.6-5 that at an orbital altitude of 140 n. mi. a change in γ from -3 deg to -2 deg reduces the required Δv by approximately 450 ft/sec.

TABLE 5.2.6-I

P37(CSM) CREW INPUTS AND PROGRAM OUTPUTS (SHEET 2 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register
14.	Time from Ignition	TFI (TF GET I)	FL V16 N45	R2 xxBxx min, sec*
15.	Middle-gimbal Angle at Ignition (a_{MG})	MGA	FL V16 N45	R3 oxx.xx deg*

*Sign convention;

γ--"-" designates below horizontal plane

θ--"+" designates north latitude, east longitude

a_{MG}--"-" indicates IMU not aligned

TFI--"-" indicates before t_{IG}; "+" after t_{IG}.

**Mass data are not specifically requested by the program—must be loaded via Routine 03 before program is allowed to proceed beyond input 5.

***VX is component of impulsive Δv, at t_{IG}, along $(\underline{R}X\underline{V})X\underline{R}$

VY is component of impulsive Δv, at t_{IG}, along $\underline{V}X\underline{R}$

VZ is component of impulsive Δv, at t_{IG}, along $-\underline{R}$.

Where $\underline{R}$ is CSM geocentric radius vector, and $\underline{V}$ is inertial-velocity vector at t_{IG}.

The scalar Δv can be observed here by keying VERB 06 NOUN 40 (R2 xxxx.xfps).

NOTE: Offset-target data relative to the Lambert-aimpoint maneuver are not displayed, but are transferred to the appropriate erasables for the applicable powered-flight guidance program.

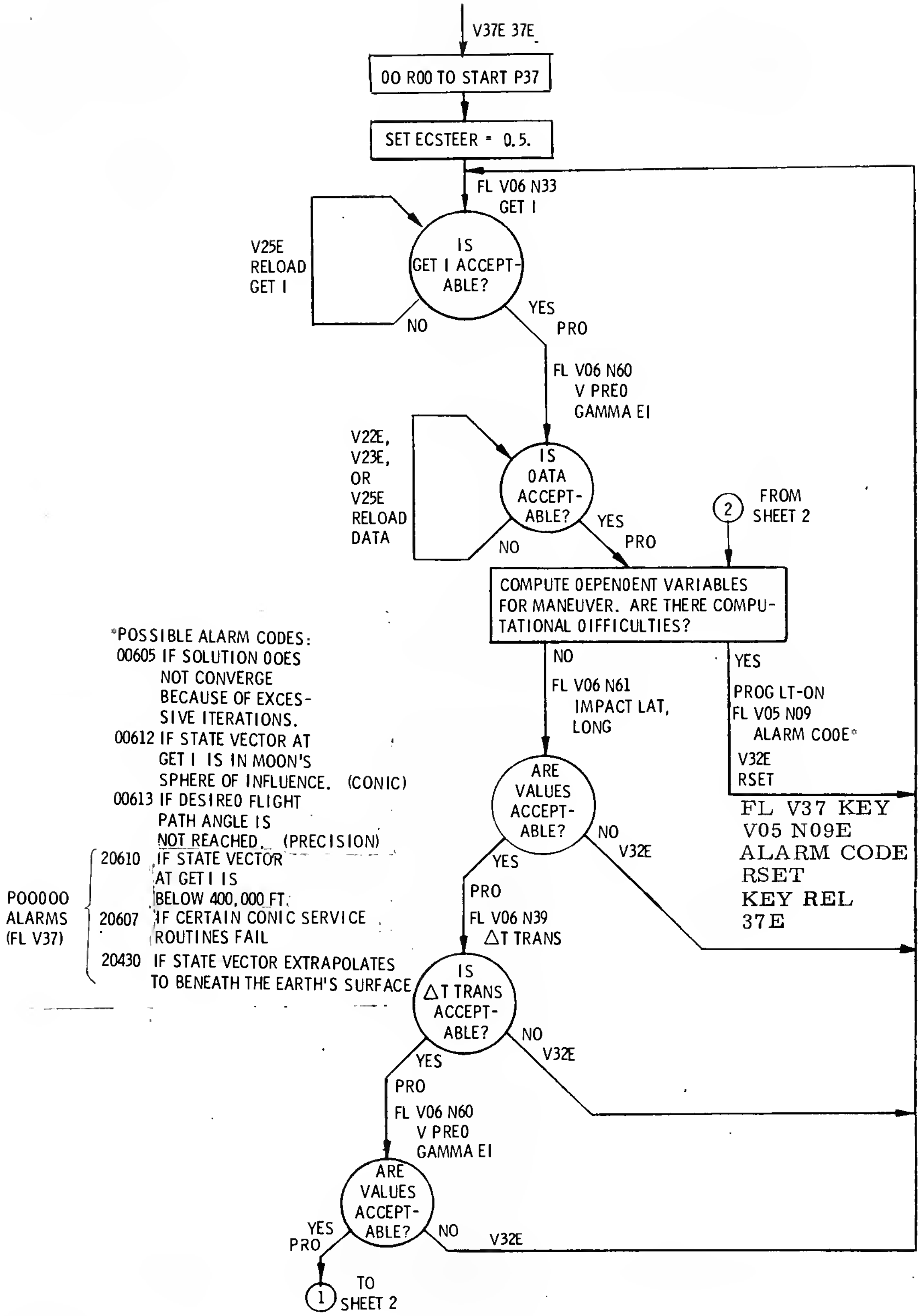


Figure 5.2.6-4. Return to Earth Program (CSM P37) (Sheet 1 of 2)

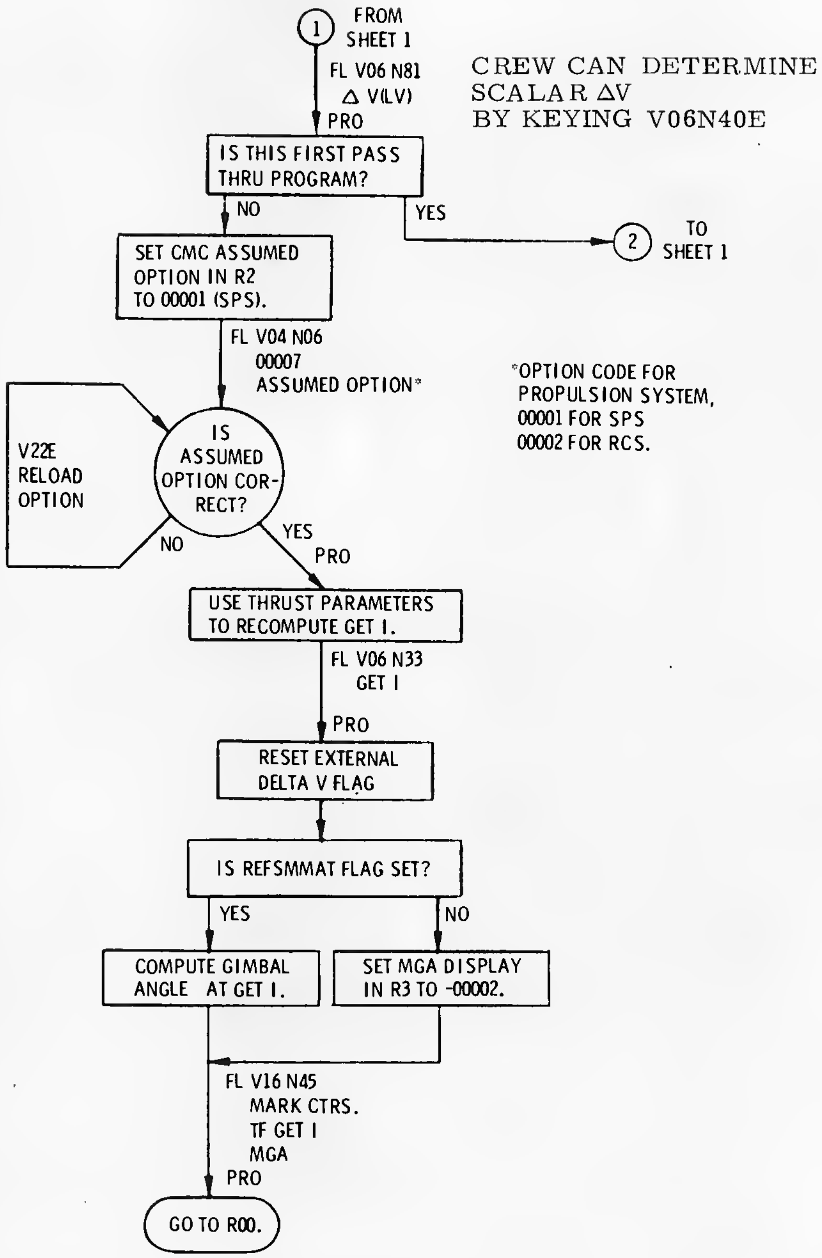


Figure 5.2.6-4. Return to Earth Program (CSM P37) (Sheet 2 of 2)

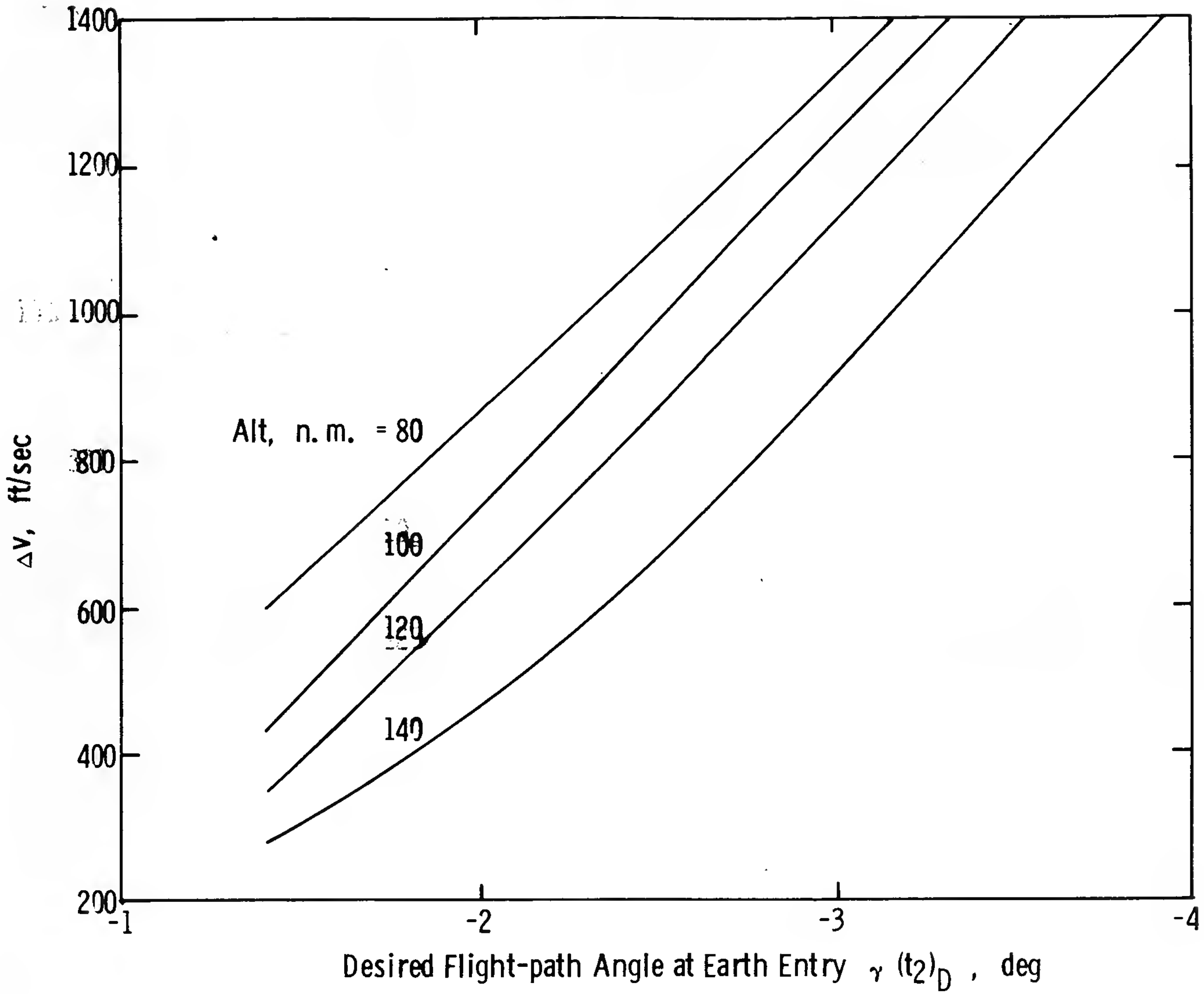


Figure 5.2.6-5. Relationship of Δv to Desired Flight-path Angle at Earth Entry: Returns from Near-circular Earth Orbits of Several Altitudes

Normally, minimum-fuel maneuvers executed during transearth coast have only an x-component (local vertical coordinates). Should the pre-maneuver state vector have a value, however, that would result in a velocity at entry $[v(t_2)]$ greater than 38,000 ± 5 fps, the program will automatically compensate for the excess velocity and produce a Δv output having both an x- and a negative z-component, i.e., a decelerating effect.

Another factor for consideration is the possibility that the minimum-fuel solution will specify a Δv that exceeds the fuel-onboard capability. Should this occur during translunar coast, the solution to the problem might be to utilize the free-return feature of the TLI trajectory and to use P37 for midcourse corrections on the way back to earth. (Figure 5.2.6-6 shows the minimum Δv required for a return from various translunar-coast distances.) During transearth coast, the minimum Δv required to adjust the entry angle increases as range decreases. Therefore, a P37 targeted maneuver should be executed as early as possible after exiting the lunar sphere of influence.

5.2.6.1.2 Minimum-Time Return.—For a minimum-time return, the crew keys into register 2 the maximum Δv obtainable with the fuel on-board. Should the Δv input be less than required for a minimum-fuel return, the program will respond as though a zero Δv_D has been entered and will compute a minimum-fuel return. Should the Δv_D input exceed P37-imposed limits, the program will automatically compute a trajectory for the maximum-allowable Δv. For example, should the Δv_D result in a $v(t_2)$ greater than 38,000 ± 5 fps, the program would automatically limit the Δv to a value resulting in a $v(t_2)$ equal to 38,000 ± 5 fps. As with a minimum-fuel return, a pre-maneuver state vector that would result in a $v(t_2)$ greater than 38,000 ± 5 fps will be corrected by a $\Delta \underline{v}$ output having both an x-component and a negative z-component. This has ramifications regarding landing-site selection and will be discussed further under that subject.

5.2.6.1.3 Adjusted-landing-site Return.—In addition to the basic options of a minimum-fuel or a minimum-time return, the crew has a limited capability of varying landing site. The salient characteristics of the capability are as follows:

a) Landing-site values (θ_{LAT}, θ_{LONG}) can either be approximations based on the AUGEKUGL routine (GSOP Section 5, paragraph 5.6.10.2), which determines time and range from entry to landing for a half-lift entry trajectory, or they can be computed using a padloaded value for entry range. (Time, however, would still be based on AUGEKUGL range.) The method used will be determined by the value entered in P37RANGE.

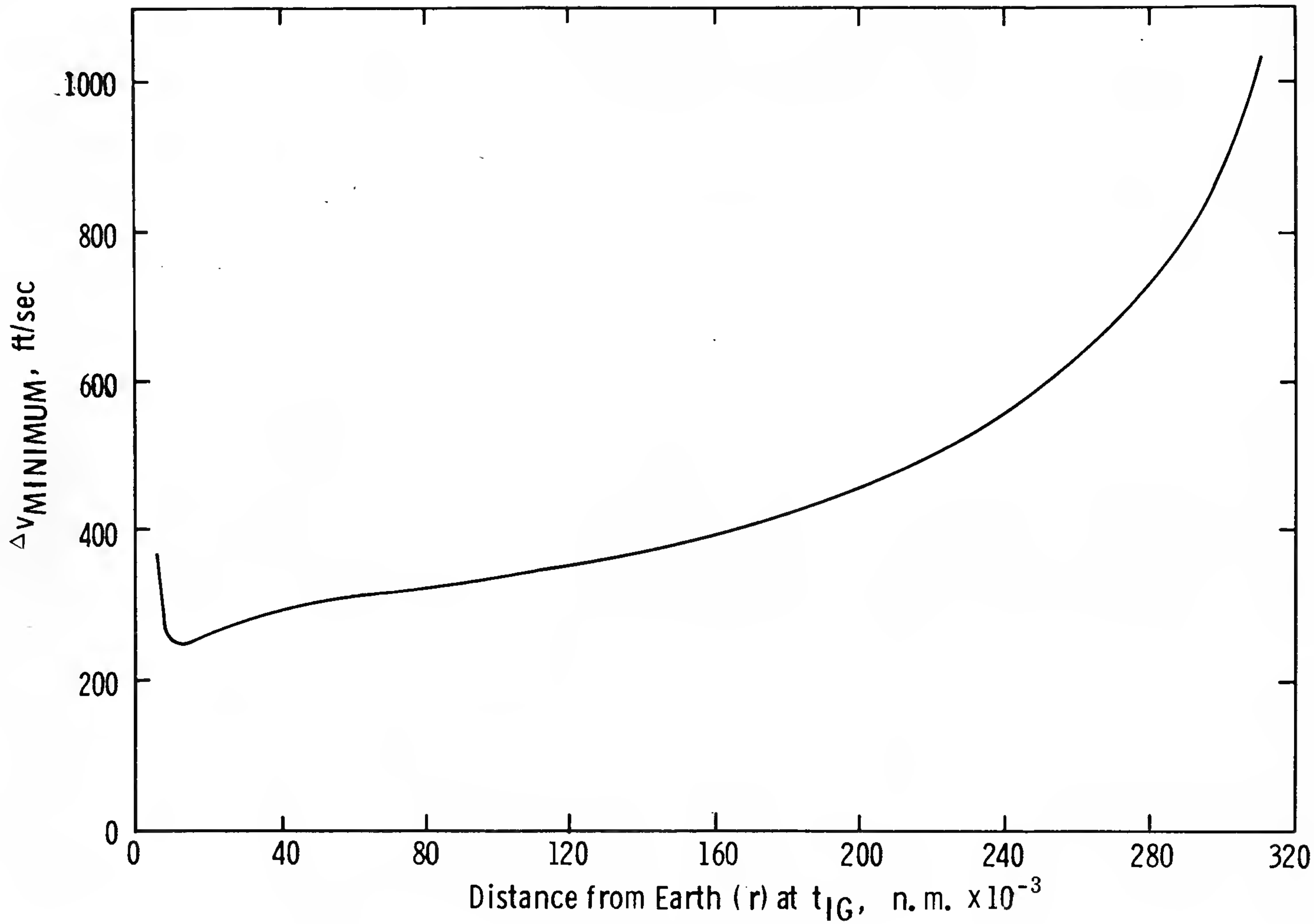


Figure 5.2.6-6 Minimum Fuel Requirements During Translunar Coast

(Table 5.2.6-II gives typical ranges and their octal equivalent. The exact octal value for any range can be computed by converting to octal the product, range times 0.758.) A zero in P37RANGE signals P37 to use AUGEKUGL to compute entry range; a specific value entered in P37RANGE signals P37 to use that value as the entry range. (Figure 5.2.6-7 illustrates AUGEKUGL entry range as a function of entry angle and velocity.)

b) The crew input most effective in varying the landing site when in earth orbit is the desired ignition time (t_{IG}), that most effective when in translunar or transearth coast is the desired velocity change (Δv_D). (See Figure 5.2.6-8.)

c) From earth orbit, landing-site adjustment is constrained by the minimum t_{21} required for completing pre-entry procedures. For example, during the apogee-to-perigee phase of the orbit (negative flight-path angle), the magnitude of t_{21} is approximately 3-1/2 minutes, which is insufficient for preparing the spacecraft for reentry; during the perigee-to-apogee phase, however, the magnitude of t_{21} is approximately 25 minutes. Therefore, we recommend that, normally, a t_{IG} be selected that will occur during the perigee-to-apogee phase. Should this prove impractical —because of landing site—the crew can extend t_{21} somewhat by selecting a shallower entry angle. (See Figure 5.2.6-9.)

TABLE 5.2.6-II

ENTRY RANGE AND OCTAL EQUIVALENT LOADED IN P37RANGE

(LOADED BY VERB 21 NOUN 01 ENTR, 3012 ENTR, xxxxx ENTR)

Range, n.mi.	Octal Equivalent
1200	01616
1250	01664
1300	01732
1350	02000
1400	02046
1450	02114
1500	02162
1550	02230
1600	02276
1650	02344
1700	02411
1750	02457
1800	02525

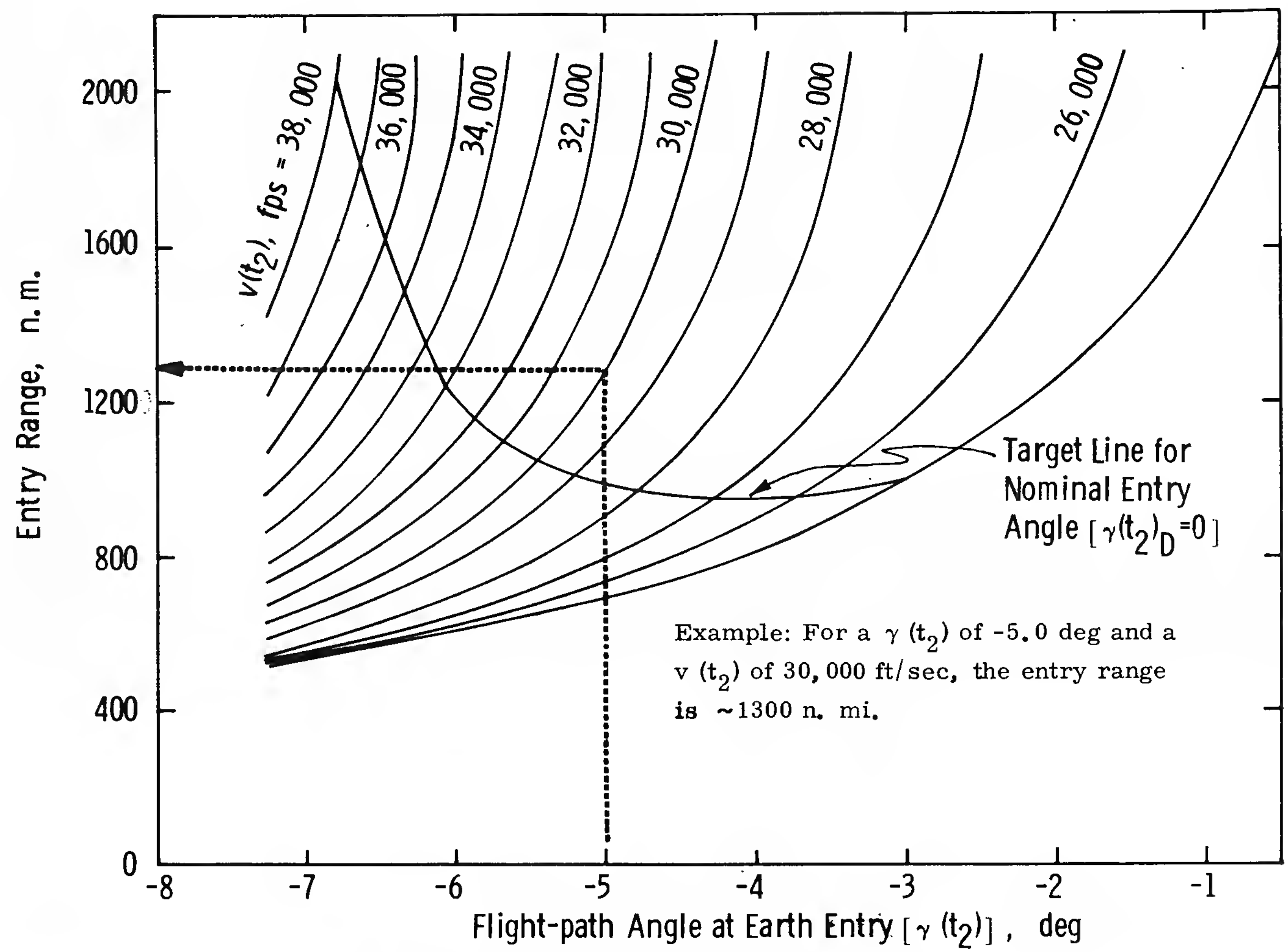


Figure 5.2.6-7. Range from Entry Interface (400,000 ft) to Landing

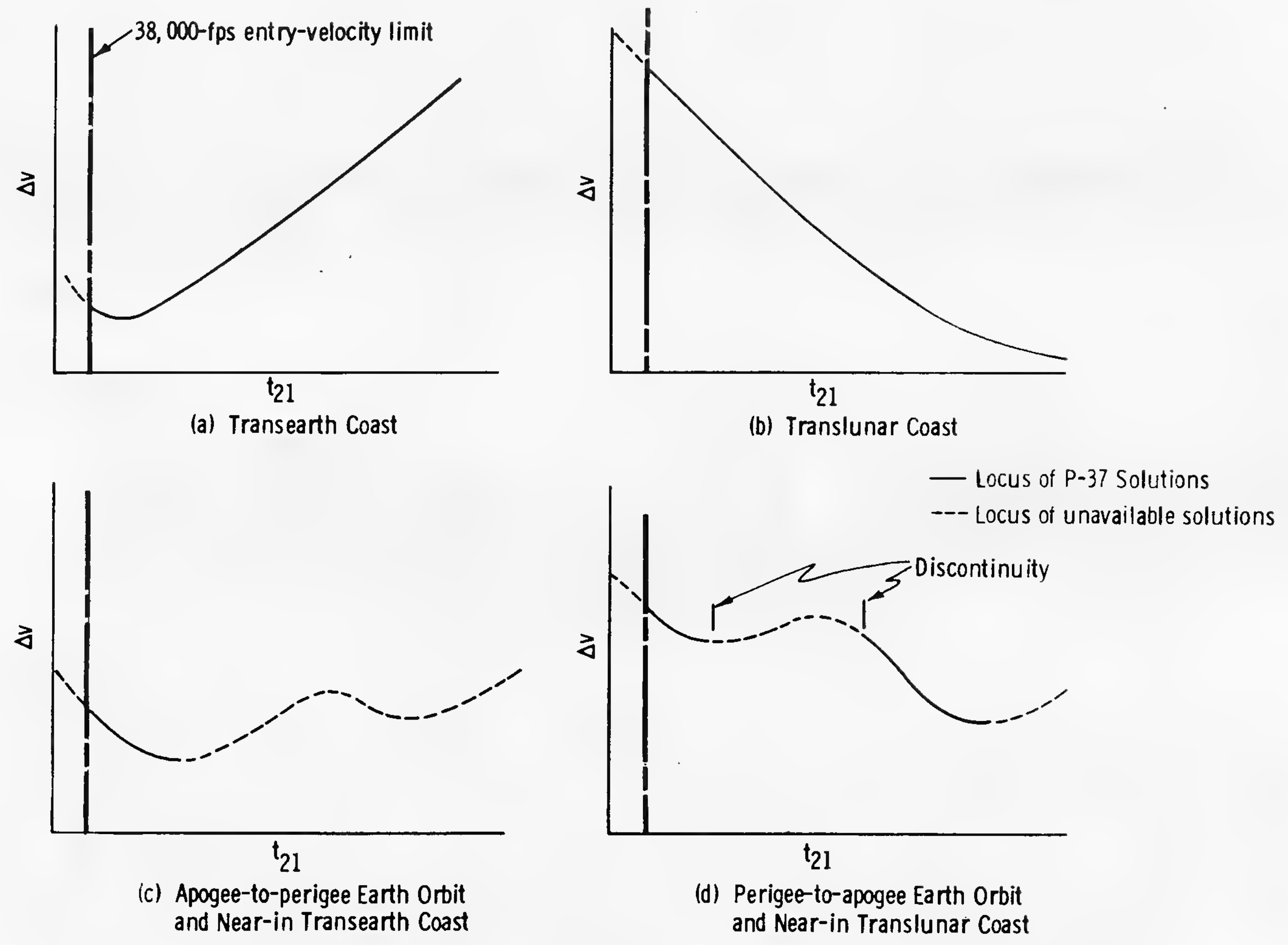


Figure 5. 2. 6-8. Locus of Available Solutions for Four Typical Pre-maneuver State Vectors

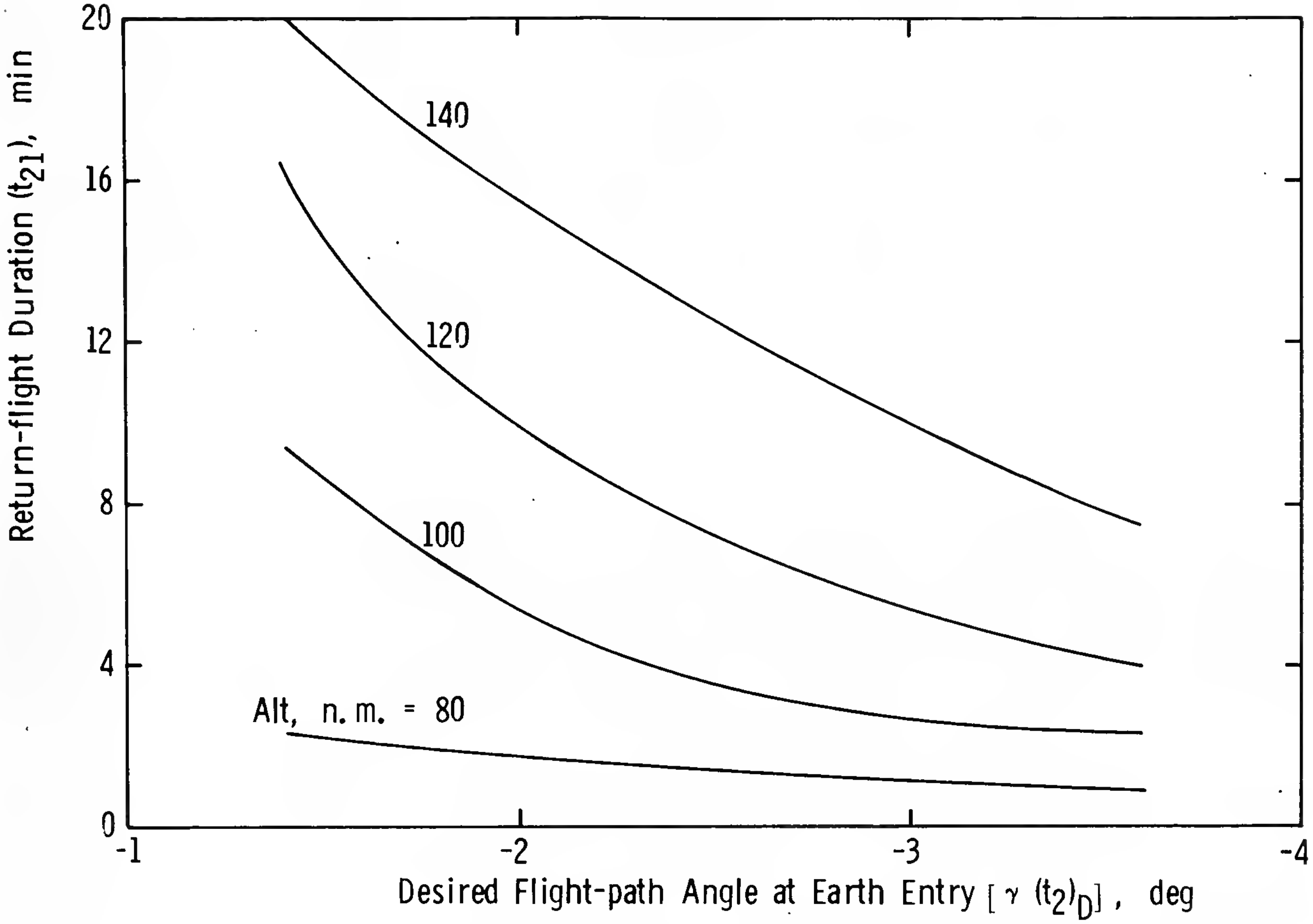


Figure 5.2.6-9. Relationship of Return-flight Duration to Desired Flight-path Angle at Earth Entry: Returns from Near-circular Earth Orbits of Several Altitudes (with Negative Pre-maneuver Flight-path Angles)

d) When return-flight durations (t_{21}) are large, i.e., several days, the precision solution may vary significantly from the conic solution. (See Figure 5.2.6-10.) The procedure recommended in that situation, for determining (1) the sensitivity of landing-site longitude to changes in Δv_D and, thus (2), the required change in Δv_D for effecting the desired adjustment in landing site, will be explained in paragraph 5.2.6.4.

5.2.6.3 Program Outputs and Computation Sequence

Regardless of option, the program computes, first, a conic solution and, second, a precision solution. (Refer to Figure 5.2.6-4.) The conic, two-body solution displays a relatively fast approximation of the return-to-earth targeting information. . In arriving at the conic solution, P37 first must extrapolate the existing state vector up to the input t_{IG}. This may take several minutes, depending upon t_{IG}. Once the state-vector has been extrapolated, the conic solution obtains within seconds. The crew can either accept the conic-solution approximations and continue with the precision solution, or the crew can vary the inputs and reiterate, as many times as necessary, for a new set of conic approximations. Except for situations that will be discussed, the conic-solution values will be sufficiently accurate for the crew to determine whether the final (precision) solution will be acceptable. The precision solution may require as little as 2 minutes and as much as 35 minutes—depending upon the trajectory. (See Figure 5.2.6-11.)

5.2.6.3.1 Program Output.—Table 5.2.6-I presents the 15 outputs displayed to the crew. The first six are the dependent variables displayed after the conic solution; the second six (outputs 7–12) are the first six recomputed, giving the precision solution. The latter are followed by a display of the burn data (outputs 13–15).

The dependent variables (outputs 1–12) are determined by crew inputs 1–3 as follows:

1. Landing-site latitude (θ_{LAT}) variability is small and only secondarily dependent upon input variables. (See in-plane-only limitation, paragraph 5.2.6.6.)

2. Landing-site longitude (θ_{LONG}) is the primary dependent variable in landing-site adjustment (paragraph 5.2.6.4).

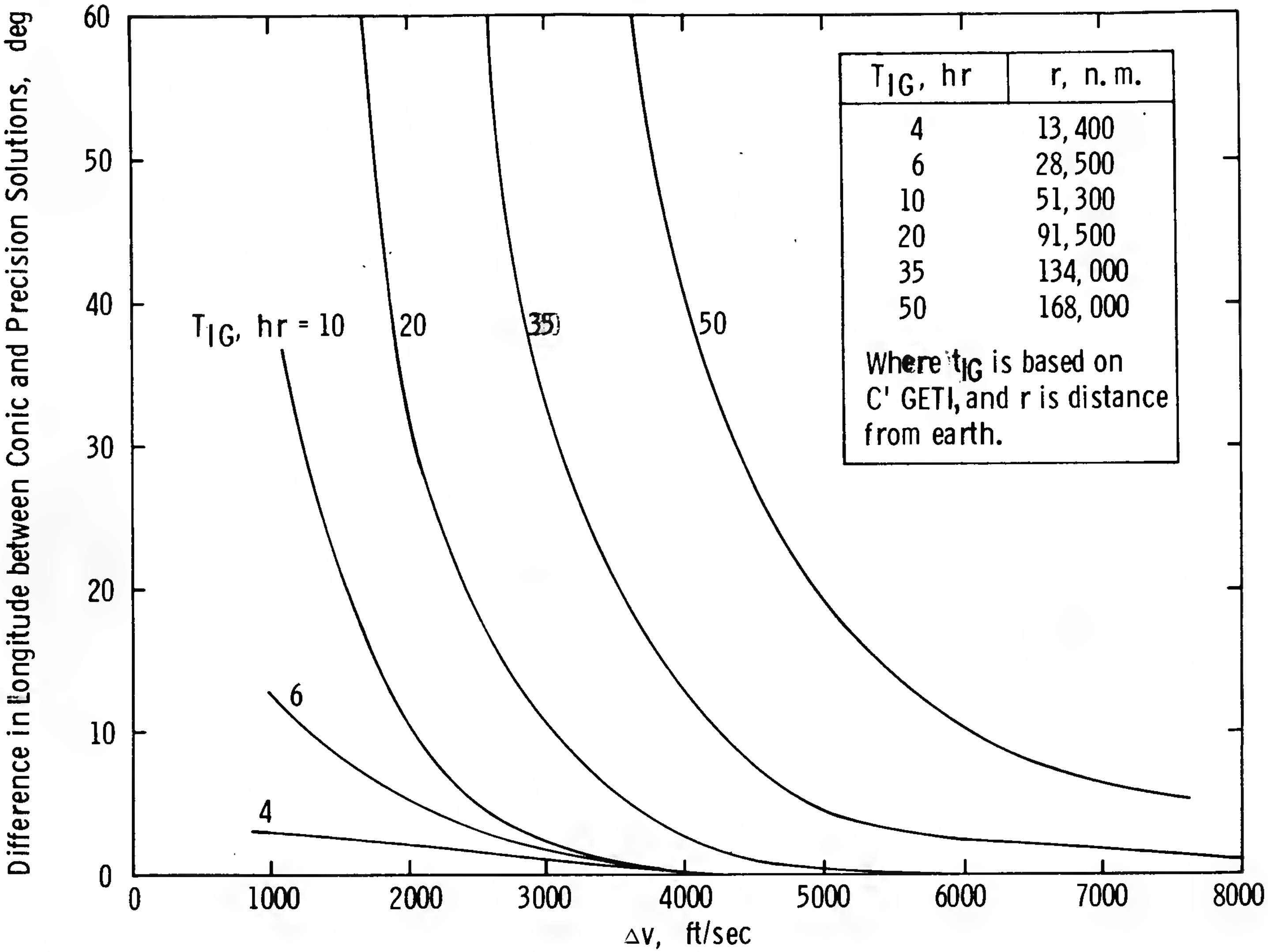


Figure 5.2.6-10. Correlation of Conic and Precision Solutions for Longitude: Returns from Translunar Coast

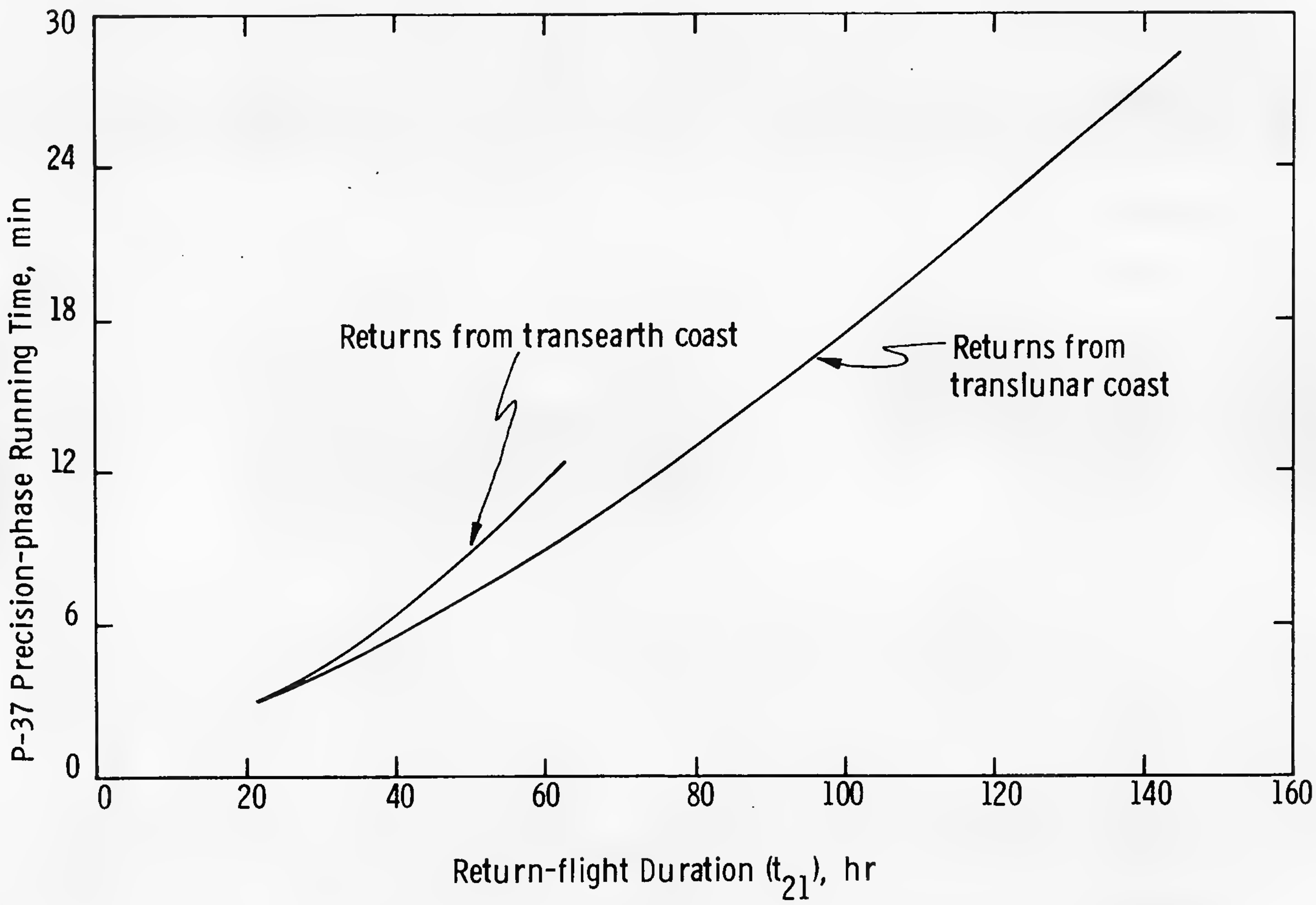


Figure 5.2.6-11. Approximate Relationship of Precision-phase Running Time versus Return-flight Duration

3. Time-of-flight (t_{21}) relative to Δv_D is illustrated for various pre-maneuver distances in Figure 5.2.6-12. Note that for minimum-fuel returns from the early part of an earth-outbound trajectory, the magnitude of t_{21} may be as much as five days for a return-through-apogee solution, but can be much less for a direct-return solution. [See special case when t_{21} may be <u>too</u> short when entering from earth orbit—paragraph 5.2.6.1.3(c).]

   For a very long t_{21}, there will be a substantial difference in the conic and precision solutions. Although rarely occurring and no cause for alarm, a large difference in conic and precision t_{21} values does introduce a special case when reiterating for landing-site adjustment—discussed in paragraph 5.2.6.4.

4. Inertial velocity at entry [$v(t_2)$] is program limited within acceptable velocities for a corresponding entry flight-path angle. As a variable, the value of $v(t_2)$ is dependent upon the input Δv_D. Should the crew request a velocity change that will result in an entry velocity exceeding the maximum allowable, the program will adjust the input Δv_D downward to ensure an output $v(t_2)$ that is within the prescribed limits. [Note that both the input scalar Δv_D and the output scalar $v(t_2)$ use the VPRED register (NOUN 60); the Δv_D magnitude can be observed, however, in VERB 06 NOUN 56 ENTR, Register 2.]

5. Entry flight-path angle [$\gamma(t_2)$] is determined by the input $\gamma(t_2)_D$. An input of zero will cause the program to automatically compute a $\gamma(t_2)$ appropriate for the computed $v(t_2)$. An input other than zero will cause the program to compute a trajectory obtaining the specifically requested entry angle. It should be noted, however, that when a value other than zero is entered, there is no assurance that the resulting trajectory will obtain the entry corridor.

6. Impulsive velocity change (Δv) is determined by the input Δv_D and is the last of the dependent variables, displayed both after the conic and the precision solutions. The display is in local vertical coordinates whose y-component is always zero. (See in-plane-only restriction, paragraph 5.2.6.6.)

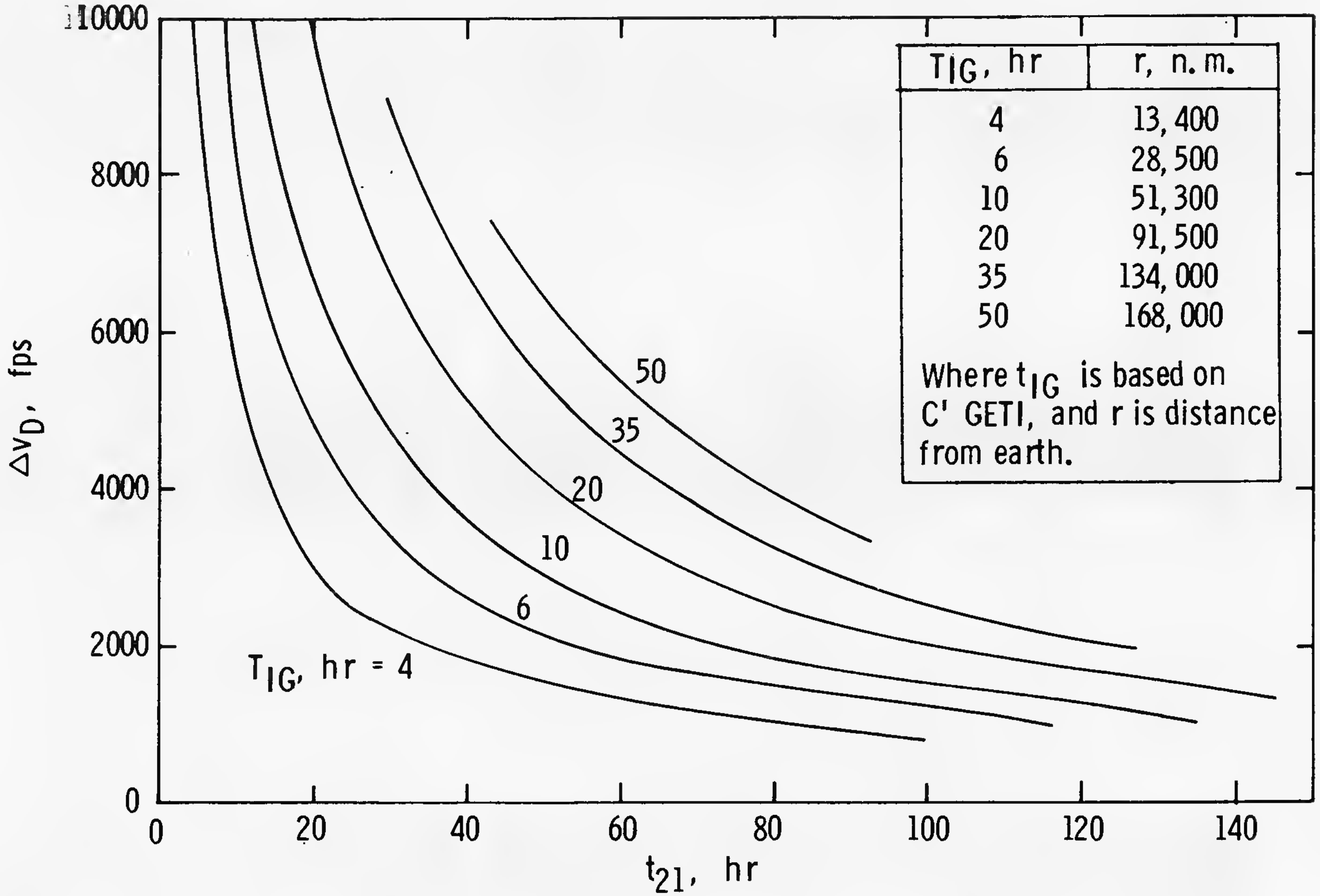


Figure 5.2.6-12. Relationship of Δv_D to Time of Flight (t_{21}) During Translunar Coast

The burn data (outputs 13–15) are displayed only after the precision solution is completed and the propulsion system has been selected. The precision time of ignition (t_{IG}) is presented to the nearest centisecond (ground elapsed time); time from ignition (TFI) is presented in minutes and seconds (maximum reading of ±59 min 59 sec); and the middle-gimbal angle (a_{MG}) at ignition is presented to the nearest 0.01 deg. Note that the output t_{IG} will not be exactly the same as the input t_{IG} since the output value is adjusted for a finite thrusting duration calculated on the basis of the propulsion system selected and the mass of the vehicle. Note also that, although TFI overflow is 59 min 59 sec, this in itself implies no limitation on how long in advance of the desired manuever time P37 can be called up. The actual TFI may, in fact, be considerably longer than the maximum indication. The limiting factor in this regard is the requirement that the state vector still be valid. (This requirement applies equally to the question of how many revolutions forward while in earth orbit the program can target an entry: subject to a valid state vector at t_{IG}, the crew can expect the targeting solution to be valid if P37 has proceeded to its conclusion without an alarm.) Finally, the crew should expect the sign value of the middle-gimbal-angle display to always be positive unless the IMU has not been aligned (REFSMMAT flag not set). If the IMU has not been aligned and a_{MG} (or MGA) cannot be computed, the value displayed will be -00002.

5.2.6.3.2 Computation Sequence.—Computation begins after the first three crew inputs into the DSKY. (Refer to Table 5.2.6-I and Figure 5.2.6-4.) Depressing the PRO key on the DSKY then signals the program to proceed with the computation of a conic-section solution, yielding the first six program outputs. By keying in VERB 16 NOUN 38, the crew has the option of monitoring the state-vector time as it extrapolates to t_{IG}. When the state vector reaches t_{IG}, the conic solution will follow within seconds. If NOUN 38 is being monitored, the DSKY will flash KEY REL.

After the conic solution has been accepted by the crew's depressing the PRO key (or reiterated by keying VERB 32 ENTR and loading new inputs), the program proceeds to recompute for a precision solution encompassing all gravitational perturbations. Outputs 7 through 12, corresponding to conic-solution outputs 1 through 6, are then displayed by the DSKY. Note that the elapsed computer time required by the precision solution is roughly proportional to the return-flight (t_{21}); e.g., for a return flight of 6 or 7 days, the precision computation time may be as much as 35 minutes; for a return from an earth orbit or from a near-in transearth trajectory, the computation time can be as little as 2 minutes. Again, by keying in VERB 16 NOUN 38, the crew can monitor the program as it converges to a solution. Normally, the state-vector time will advance from t_{IG} to the time of entry (t_2), "hunt" briefly in the vicinity of t_2, then snap back to t_{IG}, repeating the cycle as

many as seven times as the program converges to a solution. Should the state-vector time advance significantly beyond t_2 or snap back to a time earlier than t_{IG}, the crew should suspect that the solution is not converging and that it will be necessary to change t_{IG} and reenter the program. (See "Additional Restrictions," paragraph 5.2.6.6.)

The crew must enter the mass data and select the number of RCS jets (input 4) by executing R03 anytime before proceeding beyond the selection of the desired propulsion system (input 5). After the conic and precision solutions have been computed, displayed, and approved, the DSKY will display (VERB 04 NOUN 06) the option code for the service propulsion system (00001 in R2), which is the CMC-assumed option. Should the crew wish to select the reaction-control-system (RCS) option, the operator would key in VERB 22 ENTR and load (in R2) option code 00002. Before depressing the PRO key, signaling the program to proceed with the computation of t_{IG} (output 13), is the last instance when valid mass data can be entered. This information, however, will not be specifically requested by the program, which will assume as valid the last data entered. Therefore, unless R03 had been executed earlier—and the data were still valid—the crew would now key in VERB 48 ENTR, complete R03, and then continue P37 (by depressing the PRO key). Receiving a PRO signal from the crew, the program will either compute the middle-gimbal angle at ignition (REFSMMAT flag set, IMU aligned) or indicate (-00002 in register 3) to the crew that a_{MG} cannot be computed (REFSMMAT flag not set). If computed, the middle-gimbal angle at ignition will itself be displayed in R3, and the time from ignition displayed in R2. The crew's depressing the PRO key signals P37 to proceed to completion.

5.2.6.4 Procedure for Adjusting Landing Site During Cislunar Coast

For an adjusted-landing-site return from translunar coast, the crew would initially enter the maximum Δv_D available with the fuel onboard—the same as for a minimum-time return. Should the resulting landing site be unacceptable, the crew would recycle the program, adjusting Δv_D input downward, until an acceptable landing site was obtained. To assist in determining the sensitivity of landing-site longitude to variations in Δv_D, the following procedure is recommended—refer to Figures 5.2.6-13 and -14:

1. Reiterate (using Figure 5.2.6-13) the conic solution until it obtains a landing-site longitude ($\theta_{LONG_{C_1}}$) within 15 deg of desired (θ_{LONG_D}).

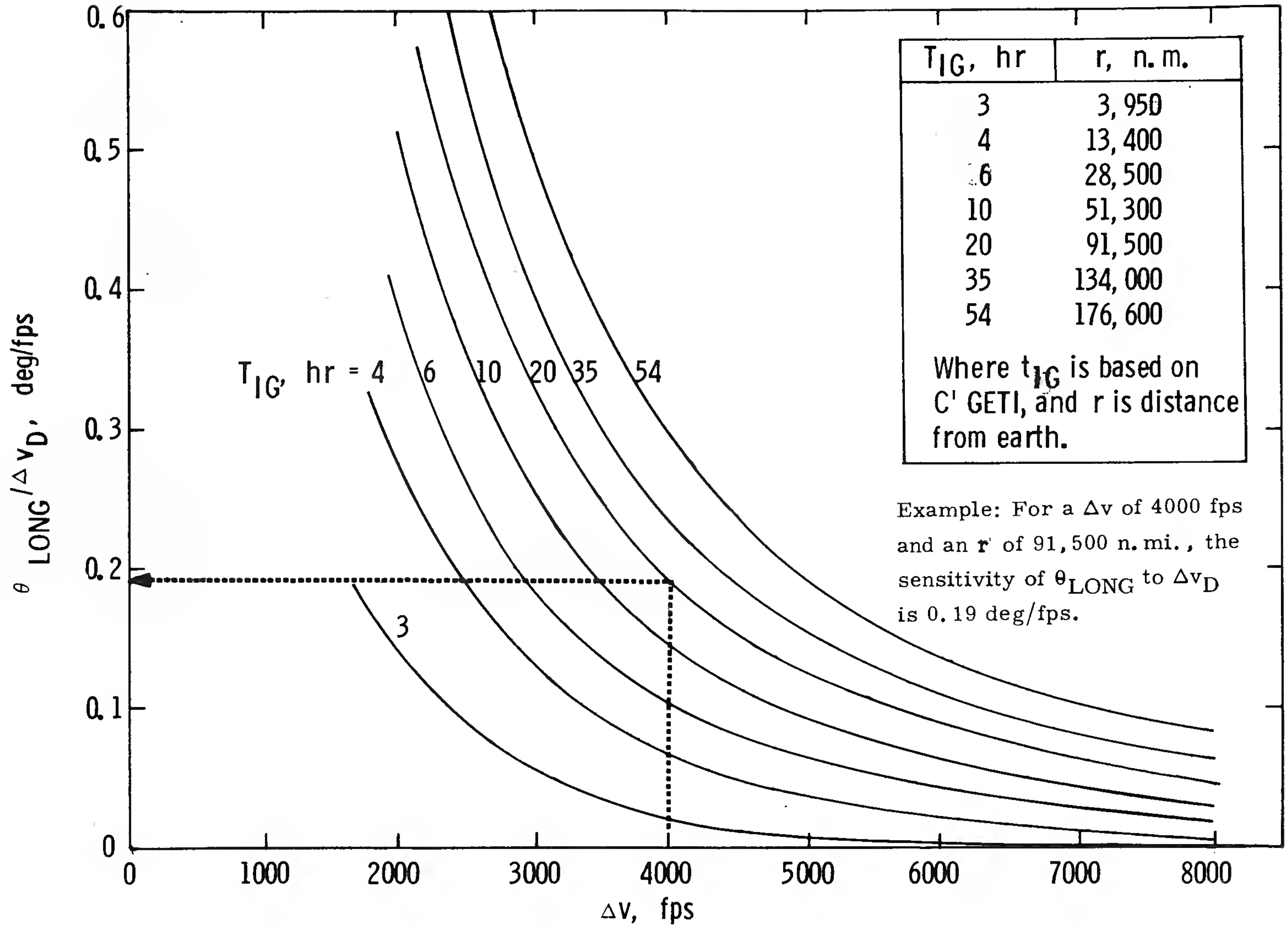


Figure 5.2.6-13. Sensitivity of Landing-site Longitude to Changes in Δv_D: Returns from Translunar Coast

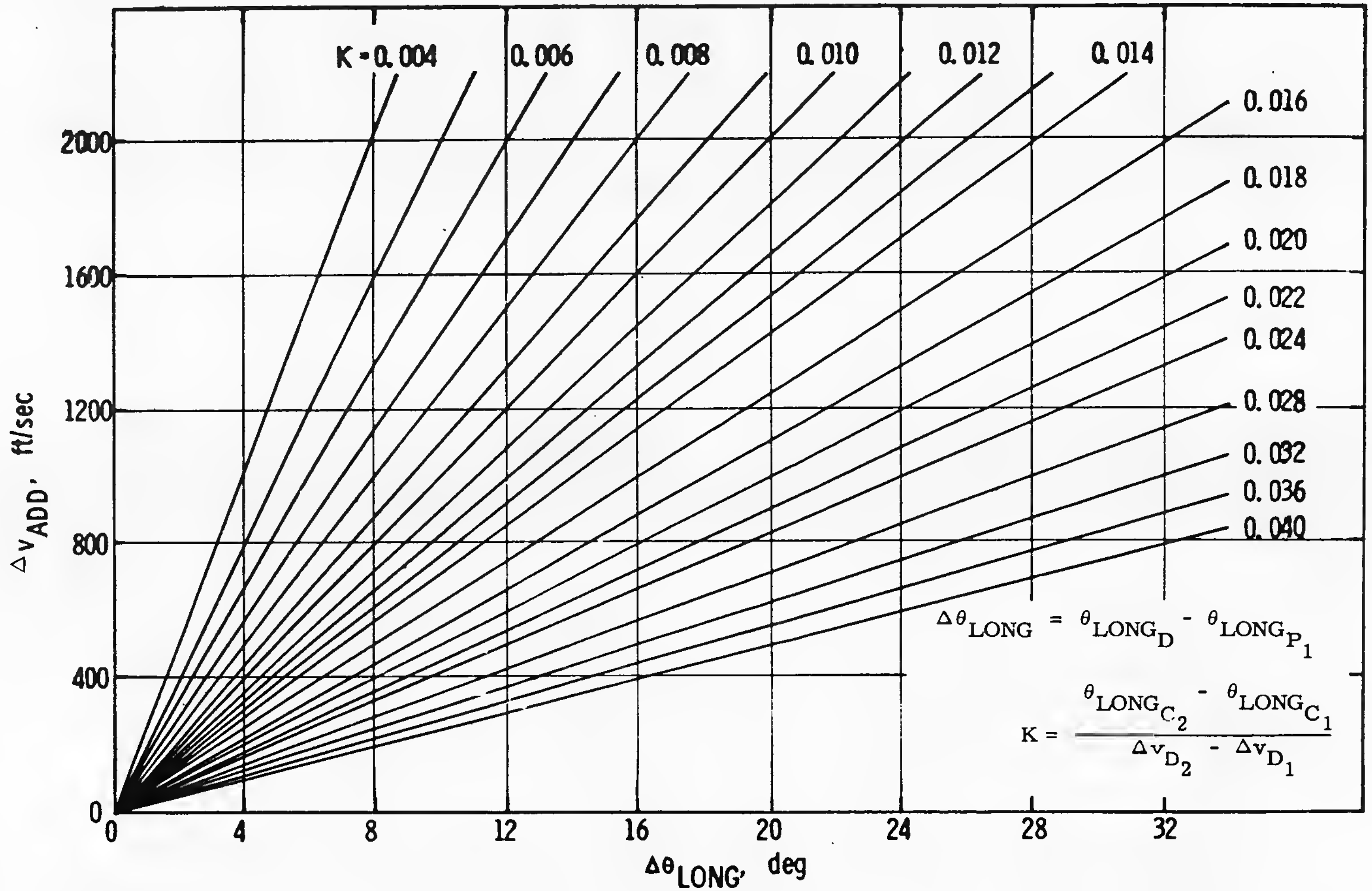


Figure 5.2.6-14a Increase in Δv_D to Produce a Desired Increase in θ_{LONG}: K = 0.04 to 0.004

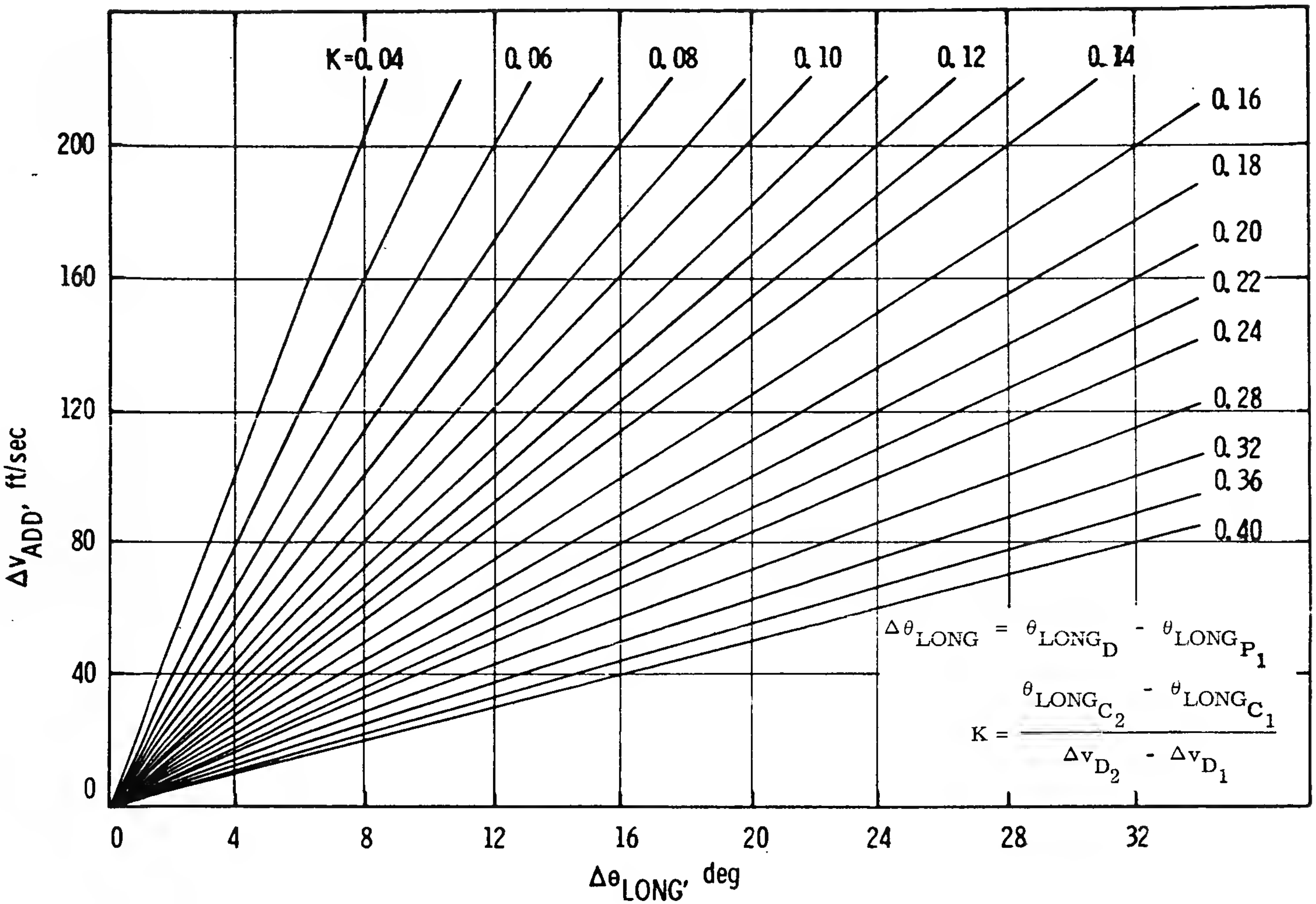


Figure 5.2.6-14b Increase in Δv_D to Produce a Desired Increase in θ_{LONG}: K = 0.4 to 0.04

2. Record $\theta_{LONG_{C_1}}$ and the last Δv_D* input (Δv_{D_1}).

3. Proceed through to a precision solution.

4. Record the precision longitude ($\theta_{LONG_{P_1}}$).

5. Add ±10 fps to Δv_{D1} (to get Δv_{D_2}), and re-run the conic.

6. Record the Δv_{D_2} and the resulting $\theta_{LONG_{C_2}}$.

7. Obtain value "K" by dividing by ±10 (viz., $\Delta v_{D_2} - \Delta v_{D_1}$) the difference in $\theta_{LONG_{C_1}}$ and $\theta_{LONG_{C_2}}$.

8. Use "K" to get from Figure 5.2.6-14 the value ($\Delta v_{D_{ADD}}$) that must be added to Δv_{D_1} in order to obtain the required $\Delta\theta_{LONG}$ (viz., $\theta_{LONG_D} - \theta_{LONG_{P_1}}$).

9. Use Δv_{D_3} (i.e., $\Delta v_{D_1} \pm \Delta v_{D_{ADD}}$) to re-run both conic and the precision solution. (Adding $\Delta v_{D_{ADD}}$ moves the landing site eastward; adding $-\Delta v_{D_{ADD}}$ moves the landing site westward.)

For an adjusted-landing-site return from transearth coast, the crew would initially enter a Δv_D input of zero—the same as for a minimum-fuel return. Recording the conic-solution longitude and the scalar Δv (VERB 06 NOUN 40), the crew would then allow the precision solution to complete. Should the precision-solution landing site be unacceptable, the crew would use the plus or minus of the Δv value observed in NOUN 40—rather than the zero Δv_D input—when adding ±10 fps to obtain Δv_{D_2}. (See step 5 of reiteration procedure used for translunar coast.) For example, if the initial Δv_D input yielded an unacceptable landing site, and the value observed in NOUN 40 (R2) were 400 fps, the crew would add (step 5) +10 fps to +400 fps, yielding +410 fps for an eastward adjustment, or would add -10 fps to -400 fps, yielding -410 fps for a westward adjustment. Steps 6, 7, 8, and 9 are performed the same as for translunar coast.

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*Near the upper limits of Δv or near the minimum-fuel Δv, adding or subtracting 10 fps to Δv_{D1} can result in a Δv_{D_2} that is outside the program-constrained limits. To detect this, the crew should monitor VERB 06 NOUN 40 (register 2) immediately after the display of the vector Δv (output 6). NOUN 40 will display the scalar value of Δv, which will be exactly equal to Δv_{D_2} unless Δv_{D_2} is outside the limits. Should the latter occur, the scalar Δv observed in NOUN 40 will be the program-limited value. The program should be allowed to complete the precision solution in order to discover whether the desired landing site is achievable with the limited Δv; if so, reiteration can be continued by adding a value less than ±10 fps to Δv_{D1}, i.e., a value that will not exceed the Δv limits.

Alternate Procedure for Adjusting Landing Site

The performance of the iterative procedure for adjusting the landing-site longitude depends upon the linearity of the relationship between the desired velocity change (Δv_D) and the transfer time (t_{21}). The transfer time, in turn, determines the landing-site longitude. Since the transfer time is more directly a function of the z-component of Δv (Δv_z), the performance of the iteration can be improved if the z-component of Δv is used as the independent variable in the iteration. This is especially true when the x- and z-component of Δv are of the same order of magnitude. When the z-component of Δv is much larger than the x-component, little improvement is likely since changes in the Δv magnitude will result in almost equal changes in the z-component.

This improvement in performance, however, is not gained without an increase in the complexity of the procedure. Since the user has no direct control over the z-component of Δv, it is necessary that he compute (P30 can be used) the desired Δv corresponding to a particular Δv_z from the following:

$$\Delta v_D = \sqrt{\Delta v_z^2 + \Delta v_x^2}$$

Δv_x remains essentially unchanged between iteration steps.

The procedure for adjusting landing site by iterating on the Δv_z component is as follows:

1. Reiterate (using Figure 5.2.6-13) the conic solution until it obtains a landing-site longitude ($\theta_{LONG_{C_1}}$) within 15 deg* of desired (θ_{LONG_D}).
   - Record θ_{LONGC_1}
   - Record the z-component of the conic-solution velocity change (Δv_{zC_1})
   - Obtain and record the conic-solution scalar Δv from NOUN 40 (Δv_{C_1}).

2. Proceed through to a precision solution

*Value used for APOLLO 14 is 12 deg. (See Basic CSM G&C Checklist, dated 1 July 1970, revised 22 October 1970.)

- Record the precision longitude (θ_{LONGP_1}).
- Record x- and z-component of the precision-solution velocity change ($\Delta v_{x_{P_1}}$, $\Delta v_{z_{P_1}}$).
- Obtain and record the precision-solution scalar Δv from NOUN 40 (Δv_{P_1}).

3. Recycle (VERB 32 ENTR)

- Compute Δv_{C_2}:

<u>TLC</u>

$\Delta v_{C_2} = \Delta v_{C_1} \pm 10$ fps (+, east)

<u>TEC</u> (to move landing site westward)

$\Delta v_{C_2} = -\Delta v_{C_1} - 10$ fps

<u>TEC</u> (to move landing site eastward)

$\Delta v_{C_2} = \Delta v_{C_1} + 10$ fps

- Load Δv_{C_2} into R2 of NOUN 60.

4. Proceed to conic solution

- Record $\Delta v_{z_{C_2}}$
- Record $\theta_{LONG_{C_2}}$
- Compute and record "K":

$$K = \left| \frac{\theta_{LONG_{C_2}} - \theta_{LONG_{C_1}}}{\Delta v_{z_{C_2}} - \Delta v_{z_{C_1}}} \right|$$

- Compute and record $\Delta\theta_{LONG}$:

$$\Delta\theta_{LONG} = \theta_{LONG_D} - \theta_{LONGP_1}$$

- Use K and $\Delta\theta_{LONG}$ to get from Figure 5.2.6-14 the value (Δv_{ADD}). (Make sign of Δv_{ADD} the same as $\Delta\theta_{LONG}$.)

- Compute and record the desired z-component of velocity change (Δv_{z_D}):

$$\Delta v_{z_D} = \Delta v_{z_{P_1}} \pm \Delta v_{ADD}$$

- Compute and record Δv_D (use P30):

$$\Delta v_D = \sqrt{\Delta v_{z_D}^2 + \Delta v_{x_{P_1}}^2}$$

(Make sign of Δv_D the same as Δv_{z_D}.)

5. Key V37E37E

- Load Δv_D in NOUN 60

6. Proceed through to a precision solution.

5.2.6.5 Program Alarms

In addition to the anticipated outputs, the program will display an alarm under the following conditions:*

a) Alarm code 00612 is displayed if the state vector at t_{IG} is within the lunar sphere of influence.

b) Alarm code 00605 is displayed if the solution will not converge.

c) Alarm code 00613 is displayed if the desired entry flight-path angle is unobtainable.

d) Alarm code 20610 is displayed if the state vector at t_{IG} is below 400,000 ft.

e) Alarm code 20607 is displayed whenever any of certain conic service routines used by P37 fail.

f) Alarm code 20430 is displayed if the state vector extrapolated either to t_{IG} (during conic phase) or to t_2 (during the precision phase) is beneath the earth's surface.

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*Alarms 00612, 00605, and 00613 are indicated by a PROG illumination, a flashing VERB 05 NOUN 09, and a display of the appropriate alarm code. Alarms 20610, 20607, and 20430 are P00D00 alarms, indicated by a PROG illumination and a flashing VERB 37. For a P00D00 alarm, the operator must key VERB 05 NOUN 09 ENTR for a display of the alarm code. To return to P37, he must depress KEY REL and RSET and then key 37 ENTR.

P37 is not capable of targeting a return when the position of the spacecraft at time of ignition is within the lunar sphere of influence (LSI). Should an attempt be made to target such a return, alarm 00612 will alert the crew that the proper solution is not possible. The corrective action is to adjust the t_{IG} input such that the spacecraft will be outside the LSI at ignition. Note that the present spacecraft position is of no consequence: so long as the spacecraft state vector at t_{IG} lies outside of the LSI, the position when P37 is called can be either within the LSI, outside the LSI, or outside but on a trajectory that passes through. Again, since the essential concern is the position at t_{IG}, the corrective action for alarm 00612 is to select a later (or earlier) t_{IG}.

Although we have not been able to simulate a likely condition resulting in a nonconverging solution (alarm code 00605), we have, nevertheless, incorporated iteration counters as a safeguard against the possibility of getting into an infinite loop. Should an alarm 00605 occur during the conic computation, the recommended corrective action would be, first, to reiterate using a specified $\gamma(t_2)_D$, i.e., other than zero; if the alarm still occurs, to reiterate using a different t_{IG}. Should an alarm 00605 occur during the precision computation, the recommended corrective action would be to reiterate with an increased Δv_D; the resulting decrease in transit time should require fewer iterations to converge on a solution. Again, the second thing to try would be to change the t_{IG}.

Although it would require lengthy explanation, we have become convinced since the original design of P37 that a condition triggering alarm code 00613 will never occur. Nevertheless, should by some remote and unforeseen circumstance the desired entry flight path not be obtainable, a possible corrective action would be either to increase the Δv_D or to adjust the $\gamma(t_2)_D$.

P37 cannot be used for targeting trajectories begun below 400,000 ft above the Fischer ellipsoid. Accordingly, the DSKY will flash VERB 37, for an alarm code 20610, should a t_{IG} be inadvertently entered that would occur below the earth-entry interface. The recommended corrective action would be to decrease t_{IG} such that it occur above 400,000 ft.

The recommended action for alarm 20607 is to check for valid inputs.

For an alarm 20430 during the conic phase, the crew would select an earlier t_{IG}; an alarm 20430 during the precision phase is rare and would be corrected by increasing Δv_D or adjusting t_{IG} in order to reduce trajectory perturbations caused by the lunar gravitational field.

5.2.6.6 Additional Restrictions

In addition to its being restricted from transfer trajectories begun within the lunar sphere of influence, the limitations of P37 are (1) it does not target trajectories begun from certain positions in the vicinity of the moon (Figure 5.2.6-15), though not within its sphere of influence, and (2) it does not target out-of-plane maneuvers. Regarding trajectories targeted from the vicinity of the moon, the number of variables precludes our defining an exact envelope of no solution. Therefore, for a return from any area approximating that shown in Figure 5.2.6-15, we recommend that VERB 16 NOUN 38 be used to monitor the program as it attempts to converge to a precision solution. Monitoring the state-vector time (as described in paragraph 5.2.6.3.2) is necessary in this instance because, though t_{IG} fall outside the LSI, the post-ignition trajectory would, if the solution converged, pass within the sphere of influence. The solution does not converge, however, nor is there an alarm; the only indication is (monitoring NOUN 38) the abnormal behavior of state-vector time. The corrective action would be to terminate integration (VERB 96 ENTR) and to reenter the program with an earlier t_{IG}, an increased Δv_D, or both.

The reason that P37 is designed to provide only in-plane solutions is to minimize fuel expenditure and program complexity. The one exception to the in-plane-only solutions is when the spacecraft is in the vicinity of the moon (though outside its sphere of influence) and there is a near collinearity of the r-vector and v-vector, viz., within 1-1/2 deg. In this situation, when the actual plane cannot be determined, an arbitrary plane is defined having the minimum possible inclination, i.e., such that the inclination of the post-maneuver orbit is equal to the angle formed by the pre-maneuver position vector and the earth's equatorial plane. Again, this occurs only when $\underline{r}$ and $\underline{v}$ are nearly collinear.

Also in the category of program limitations are the constraints regarding landing-site adjustment. The in-plane-only limitation is, itself, one constraint on landing site; consequently, the crew has very little control over the landing latitude. The second constraint is related to the discontinuity that exists regarding velocity change and transit time. For some outbound pre-abort trajectories (see Figures 5.2.6-8d and -16), the solution of the return-trajectory problem is multivalued for a given Δv_D; consequently, a small change in Δv_D may result in a change from a direct-return to a return-through-apogee solution. (See Figure 5.2.6-2.) In iterating for landing-site selection, the crew may observe, for a small change in Δv_D, a very large change in t_{21} and, of course, in landing site. As evidenced by Figure 5.2.6-16, the area in which the discontinuity can occur is quite small; encountering it, the crew has the option of iterating either for a suitable landing site within the realm

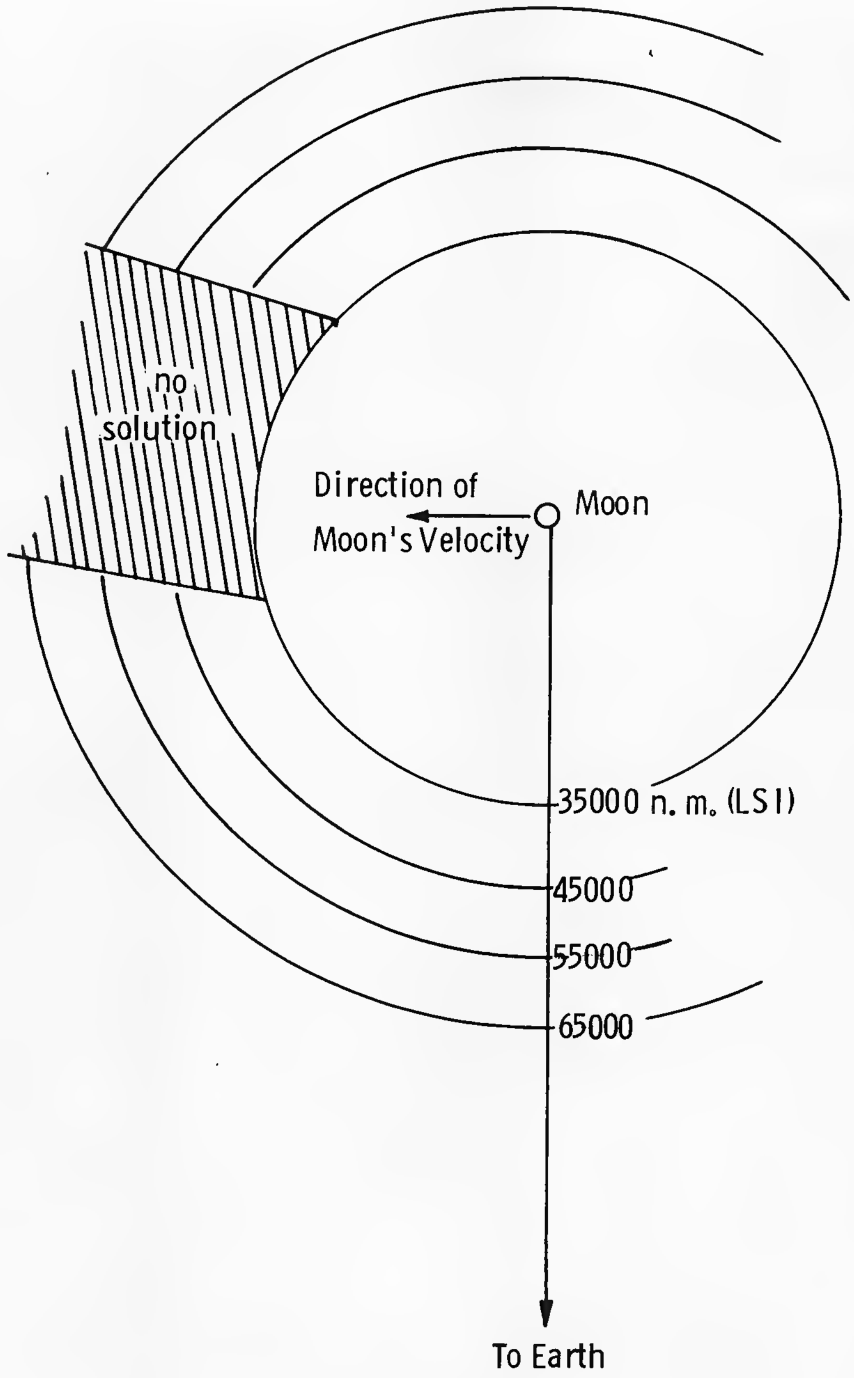

Figure 5.2.6-15. Area, Near Lunar Sphere of Influence, Where P37 Will Not Converge to a Precision Solution

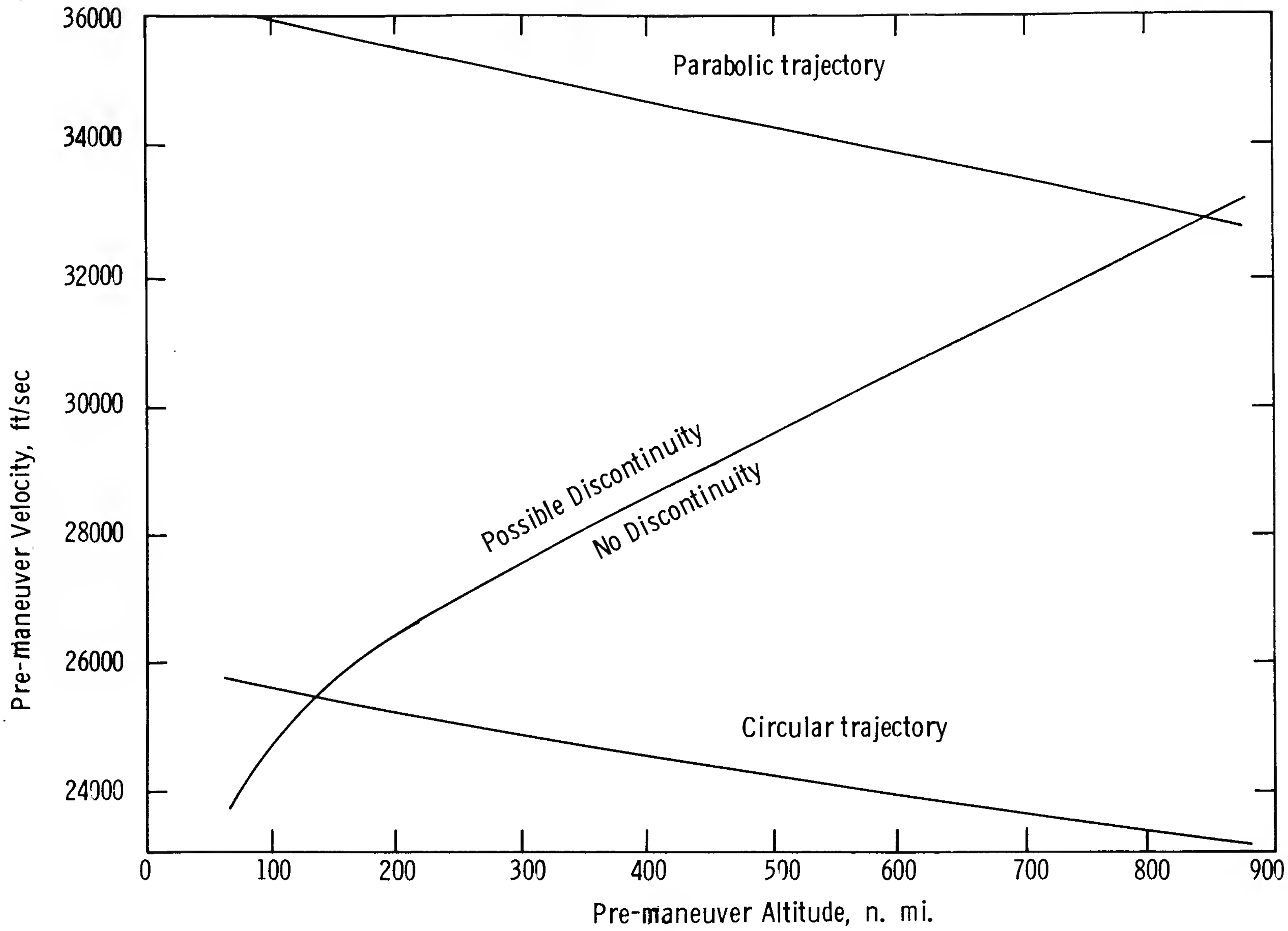

Figure 5.2.6-16. Pre-maneuver Conditions Where a Possible Discontinuity Exists in the Relationship Between Δv and Transfer Time

of direct-return solutions or for one within the realm of return-through-apogee solutions. To more precisely locate the discontinuity, the crew can reiterate for a solution using one-half the difference in the two preceding Δv_Ds. The procedure can be repeated, with progressively smaller differences in Δv_D, until the desired result is obtained.

The Return-to-Earth Program (P37) should not be performed in near-polar orbits. This is to preclude getting into the retrograde-orbit condition for which P37 will yield erroneous solutions, generally having large required-velocity changes. The retrograde-orbit problem may occur in any near-polar orbit where small disturbing accelerations (e.g., other-body and oblateness gravitation) may shift the orbital plane from posigrade to retrograde. This situation is more probable far from the earth, where the plane-defining component of velocity (i.e., that perpendicular to position) is small, and, hence, the orbital plane easily disturbed.

5.2.6.7 Program Coordination

Although the execution of P37 requires only an operational command-module computer (CMC) and does not require the inertial subsystem (ISS) to be on, timing considerations will usually best be served if the ISS is operating and the IMU is aligned before P37 is entered. Considering (1) that the ISS is required to be on for at least 15 minutes before the execution of the thrusting program (P40 or P41), (2) that normally the prethrust program (P37) requires, at most, 35 to 40 minutes to complete, and (3) that the DAP Data Load Routine (R03) must be performed before the P37 precision solution can be computed, we recommend the following as the normal sequence when timing is critical and an actual burn is anticipated:

a) Perform Autopilot Data Load (R03)
b) Perform Orientation Determination Program (P51)
c) Perform Return-to-earth Targeting (P37)
d) Begin SPS or RCS Thrusting Program (P40 or P41)
e) If the MGA displayed by P37 was greater than 45 deg, exit P40 (or P41) and perform P52 Option 1, "Preferred Orientation," as soon as the thrusting program enters the Attitude Maneuver Routine (R60) and displays the desired gimbal angles. (The crew should expect here to observe essentially the same MGA as displayed by P37.) Upon completion of P52, reenter and complete P40 (or P41). If the MGA displayed by P37 (and now R60) was less than 45 deg, but greater than zero, the crew has the option of either accepting the existing alignment, thereby conserving RCS fuel, or entering P52 to perform a "preferred orientation." Accepting the existing alignment, the crew allows the thrusting

program to continue; rejecting alignment, the crew proceeds as though the MGA had been greater than 45 deg, i.e., completes Option 1 of P52 and then reenters the thrusting program at the beginning.

The exception, when the above sequence might not be appropriate, or desired, is when a thrusting maneuver is not intended to immediately follow P37. For example, should the crew wish merely to exercise P37, without intending to use the targeting information for an actual burn, or should the crew intend a burn, but with a several-hour delay before ignition, then P37, requiring only an operational CMC, can be performed before the IMU alignment is determined. [Since IMU realignment (P52) will be necessary should more than 3 hours elapse between IMU alignment determination (P51) and t_{IG}, there is little or no advantage in this case in performing P51 before P37.] An alternate sequence, therefore, might be as follows:

a) Perform P37 through propulsion-system option selection.

b) Perform DAP Data Load Routine (R03) unless no burn is anticipated or R03 has been performed earlier.

c) Continue P37 to completion.

d) Within 3 hours of t_{IG}, perform IMU Orientation Determination Program (P51).

e) Enter SPS or RCS thrusting program (P40 or P41); when the thrusting program enters the Attitude Maneuver Routine (R60) and the DSKY flashes VERB 50 NOUN 18, "Please perform auto maneuver," observe whether the "final desired gimbal angle" is acceptable to the crew and, in any case, less than 45 deg. If the final MGA is not acceptable, exit the thrusting program and perform IMU Realign Program (P52), Option 1, "Preferred Orientation." If the final MGA is acceptable to the crew and is less than 45 deg, proceed with R60 and allow the thrusting program to continue to completion.

f) Upon completion of P52 Option 1 (unacceptable final MGA), reenter and perform SPS or RCS thrusting program (P40 or P41).

Additional factors regarding IMU alignment are related to RCS fuel economy. When a fuel-critical return using RCS thrusting is anticipated, it becomes especially important that as little RCS fuel as possible be used in aligning the IMU. Accordingly, when RCS fuel supply is critical, the crew should avoid, if possible, the necessity of entering P52. One means of avoiding the need for realigning the IMU is to visually orient the spacecraft during P51, such that the spacecraft y-axis will lie approximately normal to the $\underline{v}$, $\underline{r}$ plane, and then to coarse align the IMU to 0,0,0 gimbal angles. P51 can then be completed and the IMU left stabilized at an orientation

that should ensure a "final desired middle gimbal angle" of less than 45 deg for any trajectory targeted by P37, which computes only in-plane solutions, i.e., local-vertical thrust-vector component y = 0. Again, however, to avoid performing IMU Realignment (P52), P51 must be completed within 1 to 3 hours of t_{IG}.

5.2.6.8 Returns Using Lunar-module Descent Propulsion System (LM DPS)

Should, for some reason, the crew wish to use the LM DPS for the return-to-earth maneuver, the t_{IG} and Δv precision outputs of P37 can be used as the manually entered inputs for targeting an External-Δv burn with P30. There is, however, one important exception: in the vicinity of the moon, when $\underline{r}$ and $\underline{v}$ may be within 1-1/2 deg collinearity it may be necessary for P37 to compute an arbitrary return transfer plane (paragraph 5.2.6.6); the Δv output, in that case, would not be valid for use with P30. (Use P21 to determine flight-path angle (γ) at desired t_{IG}; if γ is within 1-1/2 deg of +90 or -90 deg, the P37 Δv cannot be used with P30.)

5.2.6.9 Restart

P37 is not restart protected. Should a restart occur, the program must be reselected and all inputs re-entered.

5.2.7—5.2.10 P72—P75 CMC Targeting of LM-active Maneuvers

The CMC programs for targeting a LM-active maneuver are P72—P75, and are identical to the CMC P32—P35 except that the choice of active vehicle for targeting computations is the LM and the passive vehicle is the CM. The CMC uses P72—P75 to target LM-active maneuvers only if the LM rendezvous radar is malfunctioning. The appropriate P7x program is then used to target the thrusting parameters for a LM-active maneuver; the parameters are voice-linked to the LM for use in the appropriate LGC targeting program, P30.

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5.2.11 P76, LM Target-Δv—CMC

P76 notifies the CMC that the LM has changed its orbit by executing a thrusting maneuver. This notification is accomplished by updating the CMC-resident LM state vector to reflect the thrusting parameters for the LM maneuver.

5.2.11.1 Inputs and Outputs

After each LM maneuver, the Command Module Pilot (CMP), using P76, updates the LM state vector by entering the LM thrusting parameters (listed below) supplied by voice-link from the LM crew. If P76 is selected by the MINKEY controller,* however, the thrusting parameters will be supplied by the CMC. These values should be compared with the voice-linked values supplied by the LM crew.

a. Δv_{LV}, the impulsive delta V in local-vertical coordinates,

b. t_{IG}, the time of ignition for the thrusting maneuver.

5.2.11.2 Procedures

Figure 5.2.11-1 presents the P76 functional flow; Table 5.2.11-I is a summary of P76 DSKY procedures.

After P76 is selected, the CMP is requested to validate the input t_{IG} (flashing VERB 06 NOUN 33). If the displayed value is the time that the LM executed the maneuver, the CMP keys PRO; if it is not the correct time, the CMP keys VERB 25 ENTR, loads the correct t_{IG}, and then keys PRO.

Next, the DSKY displays the three components of the impulsive $\Delta\underline{v}_{LV}$ (flashing VERB 06 NOUN 84) for the LM maneuver at t_{IG}. If any of the $\Delta\underline{v}_{LV}$ components are to be altered, the CMP keys VERB 2x ENTR, loads the correct $\Delta\underline{v}_{LV}$, and then keys PRO. The PRO response causes the CMC-resident LM state vector to be updated to reflect the LM $\Delta\underline{v}_{LV}$; any mark remaining in the buffer register is then invalidated, and the program exits via Routine R00.

---

*P76 is selected by the MINKEY controller following each maneuver in rendezvous, or following P36 if $\Delta\underline{v}_{LV}$ equals zero. If the CSM performed the maneuver, or if $\Delta\underline{v}_{LV}$ from P36 equalled zero, the values displayed in NOUN 84 are zero.

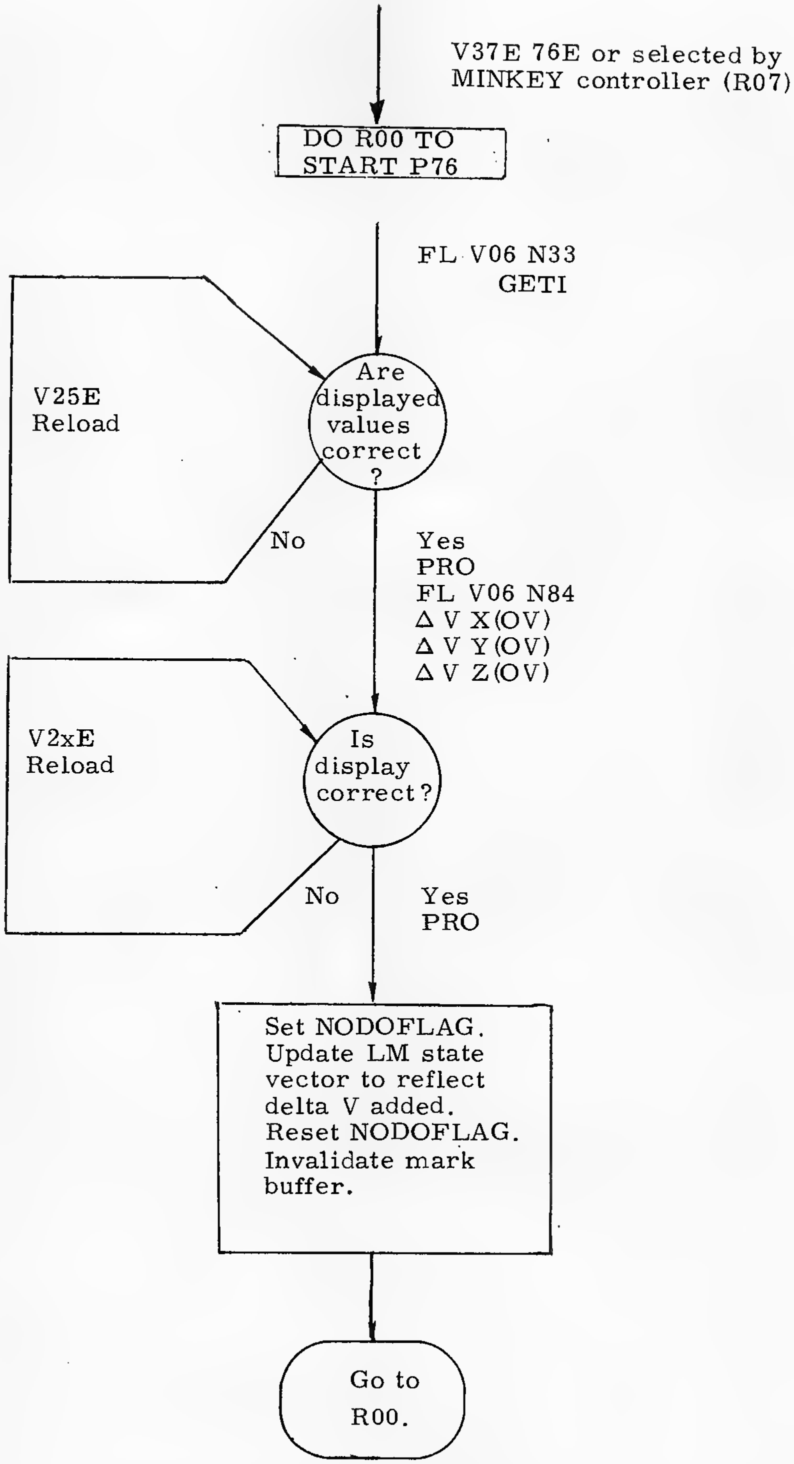

Fig. 5.2.11-1. LM Target Δv Program (CSM P76)

TABLE 5.2.11-I

SUMMARY OF LM TARGET Δv INPUTS (CSM P76)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time of Ignition, t_{IG}	GET I	FL V06 N33	R1 ooxxx. hr R2 oooxx. min R3 oxx.xx sec	Automatically displayed by P76 for crew approval. A PRO response to displayed value indicates approval of value. The GETI displayed will be that targeted for the last maneuver.
2.	Impulsive increment in velocity along the local vertical axes of the orbiting vehicle.	DELTA V(OV)	FL V06 N84	R1 xxxx.x X ft/sec R2 xxxx.x Y ft/sec R3 xxxx.x Z ft/sec	Automatically displayed by P76 for crew approval. When a PRO is keyed, the value is used by the CMC. If P76 is selected by MINKEY N84 will contain zeros if the CSM performed the last burn; if the CSM did not perform the burn, the values displayed will be the CMC-computed ΔV (LV) for the LM burn.

5.2.11.3 Coordination Procedures

To ensure that the CMC-resident LM state vector is valid during P20 navigation, the CMP should perform P76 as near the time the LM performs the maneuver as possible. Specifically, no marks should be taken during the interval between a LM maneuver and the performance of P76.

At the completion of P76, and after a new program is entered, the crew can observe the LM's new orbital parameters by calling the Orbital-parameters Display Routine (R30, paragraph 9.2.3).

5.2.11.4 Restarts

P76 is restart protected.

5.2.12 P31, Height Adjustment Maneuver—CMC

The purpose of a Height Adjustment Maneuver (HAM) is as follows: In some rendezvous conditions, involving a CSM-active Concentric Flight Plan (CFP), it may be necessary to adjust the altitude of the CSM before the coelliptic sequence (CSI−CDH) is initiated. This adjustment is to ensure that, after the CSI−CDH sequence has been performed, the desired CDH−TPI differential altitude (ΔH_{DES}) will exist.

When required, a HAM maneuver is targeted by P31 and is performed 180 degrees before the final CSI maneuver. An example of when a CSM HAM might be required is following a LM abort during powered descent, after which the LM becomes inactive.

The inputs to P31 are the same as to P32, with the addition of the desired post−CSI−CDH differential altitude (ΔH_{DES}). The value of ΔH_{DES}, an erasable constant, depends upon the specific rendezvous profile, which, in turn, depends upon the type of LM abort.

5.2.12.1 Procedures

1. VERB 37 ENTR 31 ENTR

   To initiate the Height Adjustment Maneuver (HAM) Program (P31)—Manual or MINKEY Sequencing, key VERB 37 ENTR 31 ENTR and perform P20 initialization procedures as described in paragraph 4.2.1. When initialization procedures have been completed, observe flashing display of CSI ignition time (TIG_{CSI}).

   NOTE 1.—VERB 37 ENTR 31 ENTR starts the rendezvous mode of P20, sets P31 in the mode lights and proceeds as described in paragraph 4.2.1.2.2 (Manual sequencing) or 4.2.1.2.6 (MINKEY sequencing). When P20 initialization procedures have been completed, the program proceeds to the first targeting display.

   NOTE 2.—During a multiple-CSI rendezvous with MINKEY sequencing, P31 is called, automatically, by MINKEY Controller after the penultimate CSI maneuver.

   FL VERB 06 NOUN 11

R1	00xxx.	hr (GET) TIG_{CSI}
R2	000xx.	min
R3	0xx.xx	sec

NOTE.—If P31 is the first program called in the MINKEY sequence, the crew must load TIG (CSI). If P31 is entered from a multiple CSI condition, however, the correct TIG_{CSI} will be displayed for the final CSI maneuver at NN=1.

2. VERB 25 ENTR/PRO

To change NOUN 11 values, key VERB 25 ENTR and load the desired TIG_{CSI}. To accept the displayed values, key PRO and observe flashing display of (1) the number (NN) of the post-CSI (following HAM) apsidal crossing where the constant delta altitude (CDH) maneuver is to be performed, (2) the post-CDH angle (E) between the CSM–LM line of sight and local horizontal, (3) the central angle (CENTANG) of transfer at transfer-phase initiation (TPI).

FL VERB 06 NOUN 55

R1	0000n	NN
R2	xxx.xx	deg E
R3	xxx.xx	deg CENTANG

NOTE.—Unless changed by the crew, NOUN 55 values will be NN=00001, E=208.30 deg, and CENTANG=130.00 deg. The value of CENTANG is inconsequential except as an option code: If other than zero, P31 computes a TIG_{CDH} for CSI +n (180 deg), where n is specified in R1; if CENTANG (R3) is zero, P31 computes a TIG_{CDH} for CSI +n apsides.

Normally, the CSI +n (180 deg) option is performed. If the active vehicle is in a highly elliptical orbit, however, and the apsides axes of the two vehicles are aligned, the apsides option has the advantage of allowing a horizontal CDH maneuver and smaller Δv. (The apsides axis of a circular orbit aligns with the apsides axis of any elliptical orbit. Ordinarily, the flight-plan maneuver times are selected to occur near apsides.)

3. VERB 25 ENTR/PRO

If TIG_{CDH} for CSI +n (180 deg) is desired, verify or load (VERB 25 ENTR) the appropriate values in R1, R2, and R3. If apsidal TIG_{CDH} is desired, key VERB 25 ENTR, load the desired n in R1, and load 00000 in R3. When satisfied with the NOUN 55 values, key PRO and observe flashing display of the stored TPI ignition time (TIG_{TPI}).

FL VERB 06 NOUN 37

R1	00xxx.	hr GET TIG_{TPI}
R2	000xx.	min
R3	0xx.xx	sec

4. VERB 25 ENTR/PRO

Verify displayed TIG_{TPI} against pad. To change displayed value, key VERB 25 ENTR and load correct TIG_{TPI}. When correct value is displayed in NOUN 37, key PRO and observe flashing display of TIG_{HAM}.

FL VERB 06 NOUN 33

R1	00xxx.	hr (GET) TIG_{HAM}
R2	000xx	min
R3	0xx.xx	sec

where TIG_{HAM} is computed to occur 180 deg before the final CSI maneuver.

5. VERB 25 ENTR/PRO

To change NOUN 33 values, key VERB 25 ENTR and load desired TIG_{HAM}. To accept the display values, key PRO and observe flashing display of (1) the number VHF and optics marks accumulated since the last W-matrix reinitialization, (2) time (TFI) from HAM ignition, and (3) code indicating not last pass.

FL VERB 16 NOUN 45

R1	+xxBxx	MARKs (VHF, optics)
R2	±xxBxx	min, sec (TFI)
R3	-00001	code designating not last pass

where (in R2), "-" is before TIG_{HAM}, and "+" is after TIG_{HAM}.

NOTE.—The optics MARKs counter (in R1) does not distinguish between MARKs taken by primary optics and MARKs taken by backup optics.

6. VERB 32 ENTR/PRO

Take MARKs as described in paragraph 4.2.1. To perform preliminary computation cycle, key VERB 32 ENTR and observe flashing display of rendezvous out-of-plane parameters. To perform final computation cycle, key PRO and proceed to step 9.

NOTE.—Incorporation of MARK data ceases upon crew's request for final computation (PRO to FL VERB 16 NOUN 45).

Possible ALARM

FL VERB 05 NOUN 09

R1, R2, or R3 0060x
where x = 0–6

x = 0 —no solution to TPI geometry on first iteration.

x = 1 —post-CSI pericenter altitude is less than 35,000 ft (lunar orbit) or 85 n.mi. (earth orbit).

x = 2 —post-CDH pericenter altitude is less than 35,000 ft (lunar orbit) or 85 n.mi. (earth orbit).

x = 3 —time between TIG_{CDH} and TIG_{CSI} is less than 10 minutes.

x = 4 —either the time between TIG_{TPI} and TIG_{CDH} is less than 10 minutes or the computed CDH time is greater than the input TPI time.

x = 5 —the iteration counter exceeds 15 without arriving at a solution.

x = 6 —on any two consecutive iterations, the magnitude of the CSI Δv is greater than 1000 ft/sec.

In each instance, the recovery procedure is to check input parameters and then key VERB 32 ENTR (returns to FL VERB 06 NOUN 11, step 1).

NOTE.—VERB 32 ENTR reinitializes inputs to their preset values. If the crew has changed the preset values and wishes to recheck them as a possible source of the alarm, he must do so by keying the particular NOUN of interest before recycling.

FL VERB 06 NOUN 90

R1	±xxx.xx	n.mi. Y_{CM}
R2	±xxxx.x	ft/sec Y-dot$_{CM}$
R3	±xxxx.x	ft/sec Y-dot$_{LM}$

where (in R2, R3), "+" is increasing and "-" is decreasing—

Y_{CM} is the out-of-plane distance of the CSM relative to the LM orbital plane.

Y-dot$_{CM}$ is the out-of-plane velocity of the CSM relative to the LM orbital plane.

Y-dot$_{LM}$ is the out-of-plane velocity of the LM relative to the CSM orbital plane.

7. Record/PRO

Record NOUN 90 values for transmission to LM. Key PRO and observe flashing display of components of HAM Δv (LV).

FL VERB 06 NOUN 81

R1	±xxxx.x	ft/sec Δv_X (LV)
R2	±xxxx.x	ft/sec Δv_Y (LV)
R3	±xxxx.x	ft/sec Δv_Z (LV)

NOTE. — P31 sets the value of Δv_Y (R2) to the value of (-) Y-dot$_{CM}$ in original display of NOUN 90 (step 6). This forces a node to occur 90 deg after the height-adjustment maneuver. A PC maneuver can be performed at the node in order to achieve coplanar orbits at that point. Normally, however, a PC maneuver is only performed between the last CSI maneuver and CDH.

8. PRO

To accept the values displayed by NOUN 81, key PRO and observe flashing display of (1) VHF and optics marks accumulated since the W-matrix was last reinitialized, (2) time (TFI) from HAM ignition, (3) code indicating not last pass.

FL VERB 16 NOUN 45

R1	+ xxBxx	MARKs (VHF, optics)
R2	±xxBxx	min, sec (TFI)
R3	-00001	code designating not last pass

where (in R2), "-" is before TIG_{HAM}, and "+" is after TIG_{HAM}.

NOTE.—The optics MARKs counter (in R1) does not distinguish between MARKs taken by primary optics and MARKs taken by backup optics.

9. VERB 32 ENTR/PRO

Take MARKs as described in paragraph 4.2.1. To recycle preliminary solution, key VERB 32 ENTR and return to step 6. To request final computation cycle, key PRO and observe flashing display of out-of-plane parameters.

NOTE.—Incorporation of MARK data ceases upon crew's request for final computation (PRO to FL VERB 16 NOUN 45).

Possible ALARM (See step 6)

FL VERB 06 NOUN 90

R1	±xxxx.x	n.mi. Y_{CM}
R2	±xxxx.x	ft/sec Y-dot_{CM}
R3	±xxxx.x	ft/sec Y-dot_{LM}

where (in R2, R3), "+" is increasing and "-" is decreasing. (Y_{CM}, Y-dot_{CM}, and Y-dot_{LM} are as defined in step 6.)

10. Record/PRO

Record NOUN 90 values for transmission to LM. Key PRO and observe flashing display of components of HAM Δv (LV).

FL VERB 06 NOUN 81

R1	±xxxx.x	ft/sec Δv_X (LV)
R2	±xxxx.x	ft/sec Δv_Y (LV)
R3	±xxxx.x	ft/sec Δv_Z (LV)

NOTE. — P31 sets the value of Δv_Y (R2) to the value of (-) Y-dot$_{CM}$ in original display of NOUN 90 (step 9). This forces a node to occur 90 deg after the height-adjustment maneuver. A PC maneuver can be performed at the node in order to achieve coplanar orbits at that point. Normally, however, a PC maneuver is only performed between the last CSI maneuver and CDH.

11. VERB 25 ENTR/PRO

To change the HAM Δv components, key VERB 25 ENTR and load the desired values. To accept the values displayed by NOUN 81, key PRO and observe flashing display of (1) VHF and optics MARKs accumulated since the W-matrix was last reinitialized, (2) time (TFI) from HAM ignition, (3) middle-gimbal angle (MGA) at TIG$_{HAM}$ if CSM +X-axis is aligned with initial thrust direction.

FL VERB 16 NOUN 45

R1	+xxBxx	MARKs (VHF, optics)
R2	±xxBxx	min, sec (TFI)
R3	+xxx.xx	deg MGA

where (in R2), "-" is before TIG$_{HAM}$, and "+" is after TIG$_{HAM}$.

NOTE 1.—The optics MARKs counter (in R1) does not distinguish between MARKs taken by primary optics and MARKs taken by backup optics.

NOTE 2.—If IMU is not aligned on last pass, R3 contains -00002.

12. PRO

To exit P31, key PRO. If MINKEY is operating, P31 changes W-matrix reinitialization values to 2000 ft and 2 ft/sec and proceeds as described in paragraph 4.2.1.2.6. If Manual sequencing, rendezvous continues as described in paragraph 4.2.1.2.2.

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5.2.13 P36, Plane Change Maneuver—CMC

When a plane-change (PC) maneuver is required in order to effect coplanar orbits between the CSM and LM at the end of the coelliptic sequence (CSI–CDH), the PC maneuver is targeted by P36 and is normally performed 90 deg after CSI, as computed for a CSM trajectory. (See MINKEY Rendezvous, paragraph 4.2.1.2.6 and Introduction to Targeting, subsection 5.1.)

5.2.13.1 Computations

The CMC computes PC t_{IG} to occur 90 deg after CSI and extrapolates the CSM and LM-state vectors to that time. The CMC then computes and displays the following:

1. Out-of-plane distance (Y_{CM}) of the CSM relative to the LM orbital plane
2. Out-of-plane velocity (Y-dot$_{CM}$) of the CSM relative to the LM orbital plane
3. Out-of-plane velocity (Y-dot$_{LM}$) of the LM relative to the CSM orbital plane
4. The velocity-vector change ($\Delta \underline{v}_{PC}$) required to null Y-dot$_{CSM}$ and achieve coplanar orbits.

In the MINKEY sequence, with the LM active, the crew would overwrite the computed $\Delta \underline{v}_{PC}$ with zero, causing the MINKEY controller to bypass the powered-flight program.

> NOTE.—A zero in the Δv_Y register of NOUN 81 may result in a 01301 alarm (arc sine–arc cosine argument too large) at the FL VERB 16 NOUN 45 display. To recover from the alarm, the crew would key RSET and then PRO on the FL VERB 16 NOUN 45. (See MINKEY Table 4.2.1-IV.)

5.2.13.2 Procedures

1. Key VERB 37 ENTR 36 ENTR; perform P20 initialization procedures as described in paragraph 4.2.1. When completed, observe flashing display of Plane Change initiation time (TIG_{PC}).

   > NOTE 1.—At the appropriate time during nominal MINKEY sequencing, P36 is called automatically by the MINKEY Controller. See discussion of reset points, paragraph 4.2.1.2.6.1.

NOTE 2.—VERB 37 ENTR 36 ENTR starts the rendezvous mode of P20, sets P36 in the Mode lights, and proceeds as described in paragraph 4.2.1.2.2 (Manual sequencing) or 4.2.1.2.6 (MINKEY sequencing). When P20 initialization procedures have been completed, the program proceeds to the first targeting display.

FL VERB 06 NOUN 33

R1	+00xxx.	hr (GET) TIG_{PC}
R2	+000xx.	min
R3	+0xx.xx	sec

NOTE.—TIG_{PC} computed to occur 90 deg after TIG_{CSI} (as displayed in NOUN 11).

2. PRO/VERB 25 ENTR

If satisfied with NOUN 33 values, key PRO and observe flashing display of the number of MARKs since last W-matrix reinitialization, time from ignition (TFI), and code signifying not last pass. If not satisfied with NOUN 33 values, key VERB 25 ENTR, load desired values, and then key PRO.

FL VERB 16 NOUN 45

R1	+xxBxx	VHF, Optics MARKs
R2	±xxBxx	min, sec TFI
R3	-00001	not last pass

NOTE.—Optics MARK counters (R1) do not distinguish between MARKs taken by primary optics and MARKs taken by backup optics.

Time from ignition (R2) is "-" before TIG_{PC}, "+" after TIG_{PC}.

3. VERB 32 ENTR/PRO

Take MARKs as described in paragraph 4.2.1.2.2. If recycle sequence is desired, key VERB 32 ENTR and observe flashing display of preliminary out-of-plane parameters. If final sequence is desired, key PRO and proceed to flashing display of final out-of-plane parameters (step 6).

NOTE.—Incorporation of MARK data discontinues upon crew's PRO to FL VERB 16 NOUN 45.

FL VERB 06 NOUN 90

R1	±xxx.xx	n.mi.	Y_{CM}
R2	±xxxx.x	ft/sec	Y-dot$_{CM}$
R3	±xxxx.x	ft/sec	Y-dot$_{LM}$

where (R2, R3) "+" is increasing, and "-" is decreasing.

NOTE.—If Y-dot$_{CM}$ is computed to be less than 0.1 ft/sec, Δv in NOUN 81 (step 4) is constrained as zero.

4. Record—PRO

Record NOUN 90 values for transmission to LM; key PRO when ready to proceed to flashing display of calculated components of Δv(LV).

FL VERB 06 NOUN 81

R1	±xxxx.x	ft/sec	Δv_X (LV)
R2	±xxxx.x	ft/sec	Δv_Y (LV)
R3	±xxxx.x	ft/sec	Δv_Z (LV)

where Δv_X is the X-component of impulsive Δv at TIG_{PC}; Δv_Y is the Y-component; and Δv_Z is the Z-component.

NOUN 81 (R2) contains the (-) Y-dot$_{CM}$ value of initially displayed NOUN 90 (R2). (See paragraph 5.1.5.) R1 and R3 contain zero.

5. PRO

To accept value of Δv_Y and proceed to flashing display of number of MARKs since last W-matrix reinitialization, time from ignition (TFI), and code signifying not last pass, key PRO.

FL VERB 16 NOUN 45

R1	+xxBxx	VHF, Optics MARKs
R2	±xxBxx	min, sec TFI
R3	-00001	not last pass

NOTE.—Optics MARK counters (R1) do not distinguish between MARKs taken by primary optics and MARKs taken by backup optics.

Time from ignition (R2) is "-" before TIG_{PC}, "+" after TIG_{PC}.

6. VERB 32 ENTR/PRO

Take MARKs as described in paragraph 4.2.1.2.2. If recycle sequence is desired, key VERB 32 ENTR and return to step 3. If final sequence is desired, key PRO and proceed to flashing display of final out-of-plane parameters.

NOTE.—Incorporation of MARK data stops upon crew's PRO to FL VERB 16 NOUN 45.

FL VERB 06 NOUN 90

R1	±xxx.xx	n.mi. Y_{CM}
R2	±xxxx.x	ft/sec Y-dot_{CM}
R3	±xxxx.x	ft/sec Y-dot_{LM}

where (R2, R3) "+" is increasing, and "-" is decreasing.

NOTE.—If Y-dot_{CM} is computed to be less than 0.1 ft/sec, Δv in NOUN 81 (step 7) is constrained as zero.

7. Record—PRO

Record NOUN 90 values for transmission to LM. Key PRO when ready to proceed to flashing display of calculated components of Δv(LV).

FL VERB 06 NOUN 81

R1	±xxxx.x	ft/sec Δv_X (LV)
R2	±xxxx.x	ft/sec Δv_Y (LV)
R3	±xxxx.x	ft/sec Δv_Z (LV)

where Δv_X is the X-component of impulsive Δv at TIG_{PC}; Δv_Y is the Y-component; and Δv_Z is the Z-component.

NOUN 81 (R2) contains the (-) Y-dot$_{CM}$ value of NOUN 90 (R2). (See paragraph 5.1.5.)

R1 and R3 contain zero. During MINKEY, a zero in all three NOUN 81 registers causes the automatic sequencing to bypass entrance into P52 following P36.

8. VERB 22 ENTR/PRO

To change value of Δv_Y, key VERB 22 ENTR and load the desired value. To accept value of Δv_Y and proceed to flashing display of number of MARKs since last W-matrix reinitialization, time from ignition (TFI), and the middle-gimbal angle (MGA) at TIG$_{PC}$, key PRO.

FL VERB 16 NOUN 45

R1	+xxBxx	VHF, Optics MARKs
R2	±xxBxx	min, sec TFI
R3	+xxx.xx	deg MGA

(R3 = -00002 indicates last pass and IMU not aligned.)

NOTE.—Optics MARK counters (R1) do not distinguish between MARKs taken by primary optics and MARKs taken by backup optics.

Time from ignition (R2) is "-" before TIG$_{PC}$, "+" after TIG$_{PC}$.

Middle-gimbal angle (R3) is predicted for CSM +X-axis aligned with initial thrust direction at TIG$_{PC}$.

9. PRO

To exit P36, key PRO.

NOTE.—If MINKEY is active, W-matrix reinitialization values are changed automatically to 2000 ft and 2 ft/sec. MINKEY sequence continues as described in paragraph 4.2.1.2.6. If manual sequencing, proceed as described in paragraph 4.2.1.2.2.

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5.2.14 P77, Impulsive Δv—CMC

P77 notifies the CMC that the CM has changed its orbit by executing a thrusting maneuver that was not monitored by AVERAGEG. This notification is accomplished by updating the CMC-resident CM state vector to reflect the thrusting parameters for the CM maneuver.

5.2.14.1 Inputs and Outputs

After each CM maneuver of this sort, the Command Module Pilot (CMP), using P77, updates the CM state vector by entering the following CM thrusting parameters:

a. $\Delta \underline{v}_{LV}$, the impulsive delta V in local-vertical coordinates,

b. t_{IG}, the time of ignition for the thrusting maneuver.

5.2.14.2 Procedures

Figure 5.2.14-1 presents the P77 functional flow; Table 5.2.14-I is a summary of P77 DSKY procedures.

After the astronaut selects P77 (VERB 37 ENTR 77 ENTR), he is requested to validate the input t_{IG} (flashing VERB 06 NOUN 33). If the displayed value is the time that the CM executed the maneuver, the CMP keys PRO; if it is not, the CMP keys VERB 25 ENTR, loads the correct t_{IG}, and then keys PRO.

Next, the DSKY displays the three components of the impulsive $\Delta \underline{v}_{LV}$ (flashing VERB 06 NOUN 81) for the CM maneuver at t_{IG}. If any of the $\Delta \underline{v}_{LV}$ components are to be altered, the astronaut keys VERB 2x ENTR, loads the correct $\Delta \underline{v}_{LV}$, and then keys PRO. The PRO response causes the CMC-resident CM state vector to be updated to reflect the CM $\Delta \underline{v}_{LV}$; and the program exits via Routine R00. Viewing a flashing VERB 37, the astronaut keys in the appropriate response to call the next program, e.g., 20 ENTR to call P20.

5.2.14.3 Coordination Procedures

To ensure that the CMC-resident CM state vector is valid during P20 navigation, the crew should perform P77 as near the time the CM performs the maneuver as possible. Specifically, no marks should be taken during the interval between a CM maneuver and the performance of P77.

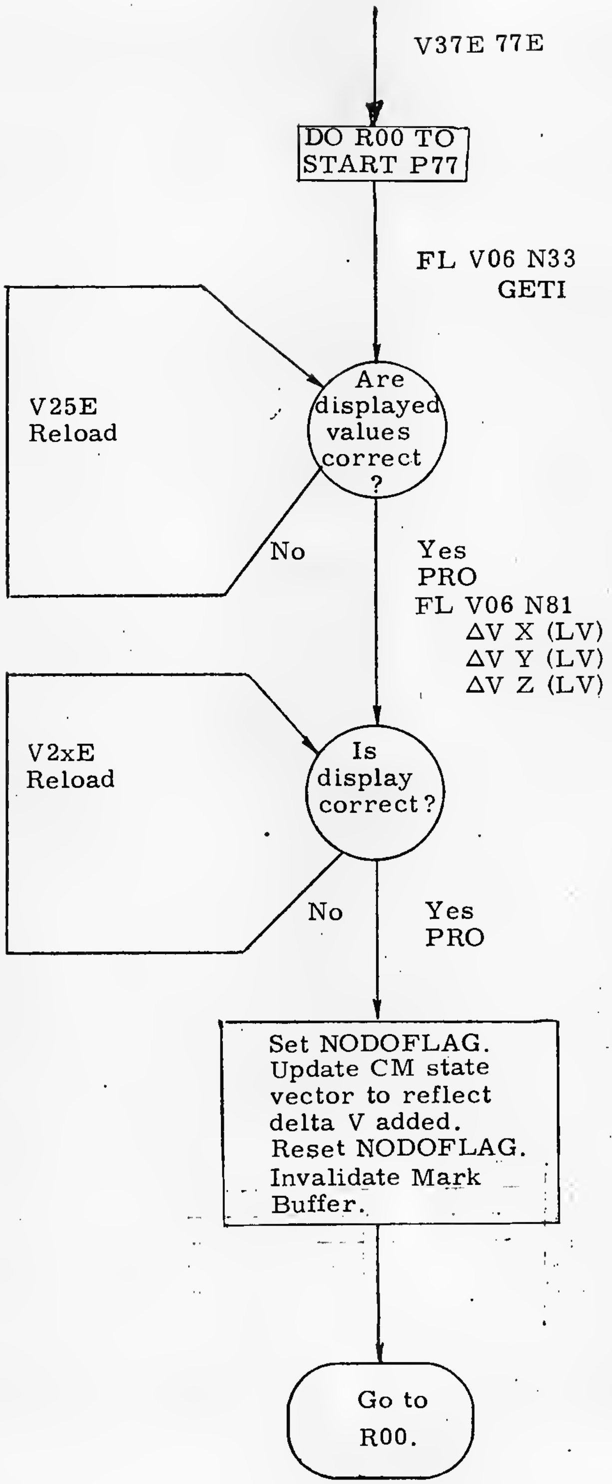

Fig. 5.2.14-1. Impulsive Δv Program (CSM P77)

TABLE 5.2.14-I

SUMMARY OF IMPULSIVE Δv INPUTS (CSM P77)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time of Ignition, t_{IG}	GET I	FL V06 N33	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec	Automatically displayed by P77 for crew approval. A PRO response to displayed value indicates approval of value. The GETI displayed will be that targeted for the last maneuver.
2.	Impulsive increment in velocity along the local vertical axes of the orbiting vehicle.	DELTA V(LV)	FL V06 N81	R1 xxxx.x X fps R2 xxxx.x Y fps R3 xxxx.x Z fps	Automatically displayed by P77 for crew approval. When a PRO is keyed, the value is used by the CMC.

At the completion of P77, and after a new program is entered, the crew can observe the CM's new orbital parameters by calling the Orbital-parameters Display Routine (R30, paragraph 9.2.3).

5.2.14.4 Restarts

P77 is restart protected.

5.3 LGC TARGETING PROGRAMS

This subsection describes the LGC programs that compute and display targeting parameters used by the LGC powered-flight programs to accomplish rendezvous. The LGC programs described are P32–P35 (paragraphs 5.3.2–5.3.5) for a LM-active rendezvous; and P72–P75 (paragraphs 5.3.6–5.3.9) for a LM-targeted CSM-active rendezvous. In addition, paragraph 5.3.1 describes P30, which is not precisely a targeting program, but a program used to prepare for a thrusting maneuver targeted by the ground. (Refer to paragraph 5.1.1.) Paragraph 5.3.10 describes LGC P76, which updates the LGC-resident CSM state vector to reflect CSM-executed thrusting maneuvers. Finally, paragraph 5.3.11 describes LGC P77, which performs the same functions as P76 for LM-executed thrusting maneuvers not monitored by AVERAGE G.

The LGC rendezvous targeting programs, like their equivalent CMC programs, are based on the concentric flight plan (CFP) rendezvous scheme. The CFP requires the active vehicle to perform three impulsive maneuvers to establish a rendezvous intercept trajectory with the passive vehicle. The first phase of the coelliptic sequence results in an active vehicle orbit that is coelliptic with the passive vehicle orbit with a nearly constant altitude differential between the two orbits. The second phase establishes and maintains the intercept trajectory until manual terminal rendezvous begins. The CFP maneuvers are targeted by the programs listed below. The targeted maneuvers are then implemented by P40, P41 and P42, the LGC powered-flight programs.

1. P32, Coelliptic Sequence Initiation (LM active) and P72 (CSM active).
2. P33, Constant Delta Altitude (LM active) and P73 (CSM active).
3. P34, Transfer-phase Initiation (LM active) and P74 (CSM active).
4. P35, Transfer-phase Midcourse (LM active) and P75 (CSM active).

Each program selects the active vehicle—either LM or CSM—depending on the program number selected by the astronaut. P32 and P33 use external Δv guidance computations, while P34 and P35 use Lambert targeting. Refer to subsection 5.1 for an explanation of these methods and a description of the advantages of each.

The nominal rendezvous maneuver sequence now bypasses the first two maneuvers of the CFP, the coelliptic sequence, to perform a direct rendezvous using the TPI and TPM maneuvers. See Figure 5.2-1. Should the phasing between the active and passive vehicles not allow direct rendezvous, the CFP is still available as backup.

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5.3.1. P30, External Δv — LGC

The LM External Δv Program is essentially the same as the CSM P30, in which the CSM is the active body. P30 accepts targeting parameters, obtained from sources external to the LGC, for the computation of required variables for the execution of the desired maneuver. Secondly, P30 displays to the crew and the ground those dependent variables necessary to the maneuver for astronaut and ground approval.

The basic assumptions are as follows:

a. The target parameters, t_{IG} (time of ignition) and $\Delta \underline{v}_{LV}$ (impulsive $\Delta \underline{v}$ along the local vertical axes) may have been uplinked during a prior execution of the LGC Update Program (P27).

b. Indication is made to the thrusting programs, by setting a flag during P30 operation, that external Δv steering is to be used.

c. The ISS need not be running or aligned for P30 to run to completion, unless radar use is desired. If so, the ISS and radar should be turned on and the radar should be locked on the CSM by the Rendezvous Navigation Program (P20). In the LM-active case, radar sighting marks will be made automatically at intervals of approximately one minute when the tracking and updating programs are enabled.

5.3.1.1 Procedures

A step by step description of crew procedures relating to P30 during its operation follows. Selection of the program is made by DSKY entry of VERB 37 ENTR 30 ENTR. Immediately, VERB 06 NOUN 33 flashes, with t_{IG} exhibited in registers 1 through 3 (in hours, minutes and seconds)—indicating that the crew is to run a comparison check on the displayed time. The criterion determining the correctness of a parameter is its agreement with values uplinked from the MSFN.

If the displayed t_{IG} is not the desired time, a new time is reloaded, using VERB 25 ENTR and loading the time into registers 1 through 3. Another comparison is made until agreement is reached. When the displayed t_{IG} is acceptable, keying PRO indicates its acceptability to the program. The program then flashes VERB 06 NOUN 81 requesting verification of the impulsive $\Delta \underline{v}$ components exhibited in the registers.

If the displayed components are not satisfactory, new components can be entered into the registers using VERB 25 ENTR; and comparison with crew desired

components continues until the satisfactory components are exhibited. At this time, PRO should be keyed. Any PRO response indicates to the program acceptance of the components and leads to the execution of certain internal program functions.

The height of the vehicle at apogee and perigee and the magnitude of the impulsive $\Delta \underline{v}$ at t_{IG} are the next parameters to be exhibited. Consultation with MSFN is made; if the parameters are not acceptable and the LGC Update Program (P27) is needed, the astronaut keys VERB 37 ENTR 00 ENTR followed by VERB 71 ENTR and the program exits to P27. If another program is desired at this point, provision is made for the keying of VERB 37 ENTR xx ENTR, and P30 exits to program number xx. Should it be desirable to recycle through the whole of P30, the crew member should key VERB 37 ENTR 30 ENTR. If the parameters are acceptable, a PRO response calls up the next display.

The last display in P30 is a flashing VERB 16 NOUN 45 with the value of the mark counter in R1, time from ignition in R2, and the middle gimbal angle in R3. A PRO response is the next action, and it terminates P30.

5.3.1.2 Computational Sequence and Inputs and Outputs

An event flow diagram of the P30 computational sequence is given in Figure 5.3.1-1. Summaries of the input and output parameters are provided in Tables 5.3.1-I and 5.3.1-II, respectively.

In the LM-active situation, all LGC inputs are uplinked to the CMC for state-vector confirmation. The CMC has the t_{IG} and $\underline{\Delta v}_{LV}$ components, which have been confirmed by the ground computer. If a disagreement should exist among the three, the burn should be postponed until new parameters can be uplinked, or any computer malfunction is diagnosed and corrected. P30 outputs, if satisfactory, are accepted as valid by keying PRO, which loads them into the computer.

The input parameters for P30 are the time of ignition, in hours, minutes and seconds, and the impulsive $\Delta \underline{v}_{LV}$, with the components displayed for confirmation in the registers. Rendezvous radar marks are relevant only if P30 is used during a rendezvous sequence with the standard targeting program exit display VERB 16 NOUN 45. Onboard out-of-plane corrections to the inputs can be loaded with corrections when these parameters are exhibited. A change is entered for each and a PRO response made. Care should be taken not to let any zero vector get into the system; other programs trying to unitize a zero vector run into alarm conditions. Out-of-plane maneuvers must have the following characteristics:

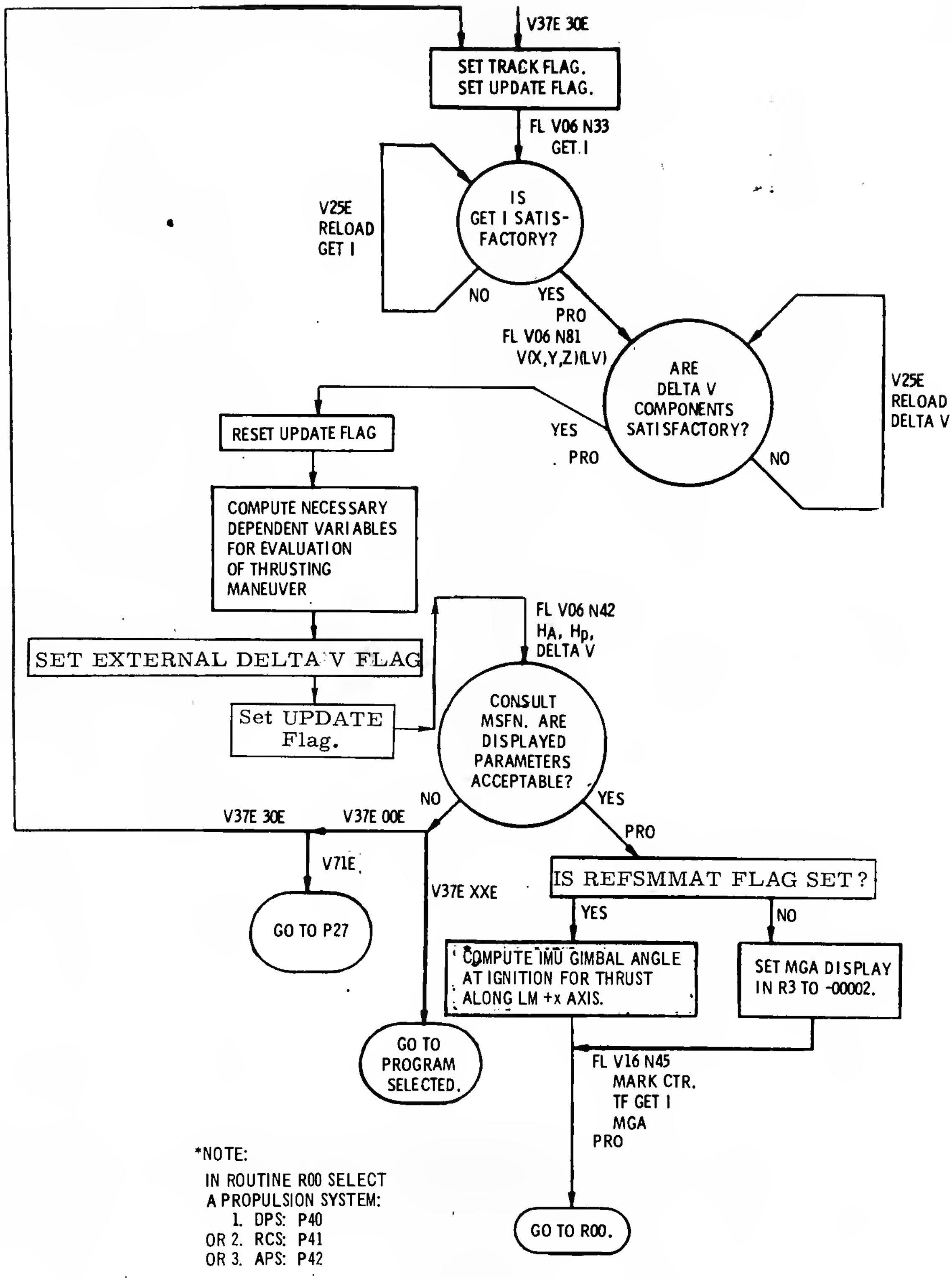

Figure 5.3.1-1. External Δv Program (LM P30)

TABLE 5.3.1-I

EXTERNAL Δv INPUTS (LM P30)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time of ignition, t_{IG}. *	TIG	FL V06 N33	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec	If the burn is uplinked, these registers will display the uplinked t_{IG}. If an onboard-calculated out-of-plane maneuver is being targeted then T(EVENT) must be loaded.
2.	Impulsive velocity change vector, $\Delta \underline{v}_{LV}$	DELTA V(LV)	FL V06 N81	R1 xxxx. x fps, X R2 xxxx. x fps, Y R3 xxxx. x fps, Z	If the burn is uplinked, these registers will display the uplinked $\Delta \underline{v}$ (LV). If an onboard-calculated out-of-plane maneuver is being targeted, then (0, $-\dot{Y}$ (LM), 0) must be loaded.

* t_{IG} (TIG) is equivalent to the GET I given in the flowchart.

TABLE 5.3.1-II

EXTERNAL Δv OUTPUTS (LM P30)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Apogee altitude above pad radius/apolune above latest landing site radius	APO ALT	FL V06 N42	R1 xxxx. x n. mi.	Maximum number (9999. 9), if scaling is exceeded.
2.	Perigee altitude above pad radius/perilune above latest landing site radius	PER ALT	FL V06 N42	R2 xxxx. x n. mi.	Maximum number (9999. 9), if scaling is exceeded.
3.	Magnitude of impulsive $\Delta \underline{v}$	DELTA V	FL V06 N42	R3 xxxx. x fps	
4.	Rendezvous marks taken	TRK MK CNT	FL V16 N45	R1 xxxxx.	Number of radar marks taken since counter was last zeroed.
5.	Time from ignition	TFI	FL V16 N45	R2 xxBxx: min, sec.	Maximum reading, 59 min., 59 sec; negative before t_{IG}, positive after t_{IG}.
6.	Middle gimbal angle	MGA	FL V16 N45	R3 xxx. xx +degrees if alignment of IMU is known; - 00002, otherwise.	

a. T(EVENT) from R36 must equal t_{IG}.

b. R1, R3 must equal 00000.

c. R2 must equal $-\dot{Y}(LM)$.

If an excessive MGA, perhaps greater than 70 deg, occurs in R3 of flashing VERB 16 NOUN 45 (output 6), the astronaut should perform a realignment. If the ISS is not running, or if its alignment is unknown (output 6 will have -00002 in R3), it must be powered up and aligned before the burn. All operations that do not call for any corrective measures before the burn will be executed by depressing the PRO key on the DSKY until the program exits through routine R00 and flashes VERB 37 for another crew action.

5.3.1.3 Exceptions and Restrictions

In the LM-active program, the time for execution of these operations is longer than it is in the CSM-active program, due to the necessity of the LGC voice-link confirmation with the CMC.

If either P40, P41 or P42 is keyed in between two P30 targeting operations for the same burn, the $\Delta \underline{v}_{LV}$ should be reloaded with the original value since the thrusting program will rotate this vector through a central angle. The thrusting program then stores this reloaded value in the original location, eliminating the unrotated vector.

WARNING: The calculation of the apogee and perigee of the orbit resulting from the P30-targeted maneuver is based on an impulsive Δv, and can be very wrong for maneuvers of long duration.

5.3.1.4 Restarts and Alarms

P30 is restart protected. There are no alarm conditions.

5.3.2 P32, Coelliptic Sequence Initiation (CSI)—LGC

Coelliptic Sequence Initiation is the first targeting program in the concentric flight plan (CFP). The program calculates the targeting parameters associated with the first two maneuvers of CFP, the coelliptic sequence, and stores these values for use by the desired LGC thrusting program—P40, P41 or P42. The calculations made by P32 are based on maneuver data approved and keyed into the LGC by the crew. The program, in turn, displays to the crew and to the ground—for approval —dependent variables associated with the concentric flight plan maneuvers.

> NOTE.—The present nominal (direct) rendezvous trajectory calls for maneuvers targeted by the Transfer-phase Initiation Program (P34) and the Transfer-phase Midcourse Program (P35). The coelliptic sequence, comprising P32 and P33, is not used. When a direct rendezvous cannot be made without first adjusting the phasing between the active and passive vehicles, however, the concentric flight plan is still available. Refer to subsection 5.2.

P32 computes a horizontal external Δv maneuver for CSI parallel to the plane of the passive vehicle at t_{IG}(CSI). The crew-specified inputs to P32 are listed below. Criteria used to select input values are the conditions at orbital injection, as well as terminal lighting conditions.

a. Time of the CSI maneuver (may be zero or negative; see Section 4, Luminary GSOP)
b. Time of the terminal-phase maneuver (TPI)
c. The elevation angle (E) of the line of sight to the passive vehicle referenced to the horizontal plane at t_{IG} (TPI)
d. The number of apsidal crossings (N) after CSI that the CDH maneuver is to occur.*
e. CENTANG, used as option code (See Section 4 Luminary GSOP).

The program uses the on-board estimates of the state vectors and an iteration technique to solve for the velocity change at CSI required such that the terminal-phase conditions of the desired elevation angle are achieved. The crew is then provided with outputs, which include differential altitude at t_{IG} (CDH); the time between CSI and CDH; the time between CDH and TPI; and the velocity change for CSI and CDH in local vertical coordinates.

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*An out-of-plane maneuver may be performed between CSI and CDH.

5.3.2.1 P32 Rendezvous Navigation

The LGC Rendezvous Navigation Program (P20) performs automatic acquisition with the radar, automatic reading and processing of the radar data, and preferred attitude tracking.

Like the other LGC rendezvous targeting programs, P32 is designed to run while P20 is operating in the background. P20 improves the estimate of the state vectors of the two vehicles with respect to each other—upon which P32 calculations depend. Moreover, since P32 is performed after injection or abort—situations providing a poor initial estimate of the LM state vector—a number of radar marks should be taken before final computation in P32 to improve the onboard estimate. The number of marks taken is mission-dependent. Refer to paragraph 4.3.1 for a description of P20 and coordination procedures with the targeting programs.

5.3.2.2 Discussion of Inputs and Outputs

Table 5.3.2-I lists the input displays of P32. Under nominal conditions, program inputs are given to the crew by ground. If an alarm occurs, the crew should key RSET and recycle the program to check input. If the input was good, crew should follow procedures described in paragraph 5.3.2.4. If the solution appears incorrect, although no alarms have occurred, the crew should reselect the program via VERB 37 ENTR 32 ENTR to check input.

The first input value, t_{IG}(CSI), the time of CSI ignition, is displayed by a flashing VERB 06 NOUN 11. Initially, t_{IG}(CSI) may be zero or negative; any positive non-zero value entered by the crew is used as the time of ignition after PRO is keyed. If PRO is keyed with the zero or negative value, however, P32 computes and displays t_{IG}(CSI) for the next apoapsis. A PRO response incorporates the value into the LGC calculations.

Table 5.3.2-II lists P32 output. The VERB 16 NOUN 45 display (listed as outputs 1–3 on Table 5.3.2-II) shows the status of rendezvous navigation in the LGC. R1 shows the number of marks incorporated since the latest significant event in P20; this information helps to determine when the W-matrix should be reinitialized, and how many more marks should be taken with the current W-matrix, as specified by mission procedures. R2 shows how much time is left before ignition to take marks and perform final P32 computation. R3 indicates whether the LGC will accept marks. If R3 equals -00001, final computations have not been made by the LGC and marks will be incorporated if taken during any flashing non-alarm display. If the astronaut

TABLE 5.3.2-I

COELLIPTIC SEQUENCE INITIATION CREW-SPECIFIED INPUTS (LM P32)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time of CSI ignition	TIG(CSI)	FL V06N11	R1 ooxxx. hr R2 oooxx. min R3 oxx.xx sec	Astronaut must load TIG(CSI). If the time is zero, or negative, the program computes it as the time of the next apoapsis, subject to astronaut modification.
2.	The number of the post-CSI apsidal crossing of the active vehicle at which t_{IG}(CDH) should occur, or the number of post-CSI maneuver orbital half periods at which t_{IG}(CDH) will occur.	N	FL V06N55	R1 xxxxx.	N is usually the first input to change when alarm conditions arise. (See section on alarms.)
3.	Elevation angle. The angle between the LM/CSM LOS and the LM local horizontal at t_{IG}(TPI) referenced to the direction of flight.	E	FL V06N55	R2 xxx.xx deg	
4.	Orbital central angle of the passive vehicle during transfer from t_{IG}(TPI) to time of intercept.	CENTANG	FL V06N55	R3 xxx.xx deg	<u>Note</u>.—The LGC uses R3 only as an option code. For an R3 value other than 00000, the LGC calculates for a t_{IG}(CDH) at N(period/2) from CSI.
5.	Time of TPI ignition	TIG(TPI)	FL V06N37	R1 ooxxx. hr R2 oooxx. min R3 oxx.xx sec	Astronaut must load t_{IG}(TPI). t_{IG}(TPI) minus t_{IG}(CSI) ought to be at least 70 minutes for lunar orbit, when the 180-degree option is used. An absolute minimum would be 25 minutes. If N is increased, t_{IG}(TPI) must be increased.

NOTE.—To accept the value displayed, the astronaut should record value and key PRO. To change the displayed values, he keys VERB 25 ENTR and loads desired values.

TABLE 5.3.2-II

COELLIPTIC SEQUENCE INITIATION OUTPUT DISPLAYS (LM P32) (Sheet 1 of 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1.	The number of marks made since RR tracking mark counter was zeroed. See paragraph 4.3.1.	M	FL V16N45	R1 xxxxx.	VERB 32 ENTR starts computation process using latest update of state vector. PRO terminates mark process and starts final computation.
2.	Time from t_{IG}(CSI)	TFI	FL V16N45	R2 xxBxx min, sec	Maximum reading is 59B59. Sign is minus before and plus after t_{IG}(CSI).
3.	Middle gimbal angle at t_{IG}(CSI) if LM + X axis is aligned with initial thrust direction.	MGA	FL V16N45	R3 xxx.xx deg	a. Value is -00001 except during last pass through P32. b. Value is -00002 on last pass through P32 if IMU is not aligned. c. xxx.xx deg MGA is displayed on last pass if IMU is aligned.
4.	The altitude between the active and passive vehicle orbits at t_{IG}(CDH). Sign is plus when the active vehicle is below the passive vehicle.	DELTA ALT (CDH)	FL V06N75	R1 xxxx.x n.mi.	Normal response to VERB 06 NOUN 75 is PRO.
5.*	t_{IG}(CDH) minus t_{IG}(CSI)	DELTA T (CSI/CDH)	FL V06N75	R2 xxBxx min, sec	Computed in hours, minutes, and seconds, of which only the minutes and seconds are displayed.**
6.*	t_{IG}(TPI) minus t_{IG}(CDH)	DELTA T (CDH/TPI)	FL V06N75	R3 xxBxx min, sec	Computed and displayed same as output 5.**

*t_{IG}(CDH) is available by keying VERB 06 NOUN 13 ENTR.

**R2 and R3 are modularized to the hour.

TABLE 5.3.2-II

COELLIPTIC SEQUENCE INITIATION OUTPUT DISPLAYS (LM P32) (Sheet 2 of 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
7.	Components of impulsive velocity change for CSI.	DELTA V (LV) (CSI)	FL V06N81	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	Crew now has the option to define $\Delta v(LV)$ components for subsequent thrusting maneuvers. Will normally exercise this capability to correct out-of-planeness by first selecting R36 (V90E) and then modifying $\Delta v(LV)$.
8.	Components of impulsive velocity change for CDH.	DELTA V (LV) (CDH)	FL V06N82	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	NOTE.—If the impulsive velocity change for CSI (output 7) was modified by crew, the modification will not be reflected in the LGC-computed values for CDH (output 8) displayed here.

wishes to terminate the marking process and use the current LGC estimate of the state vector he should key PRO in response to a VERB 16 NOUN 45 display. After a PRO response to this display, no more marks will be incorporated. The computer will calculate the burn parameters for a final time, display the other outputs, and then redisplay VERB 16 NOUN 45, with the IMU status indicated in R3. If the alignment is unknown, R3 equals -00002. Otherwise, the MGA at t_{IG}(CSI) is shown as a positive number. A second PRO response to the VERB 16 NOUN 45 display then terminates the program via Routine 00. Recycling using VERB 32 ENTR at this point is useless because no parameters will change (no marks can be accepted). The astronaut must wade through the other outputs before he can reach Routine 00.

Output 4—the altitude between the active and passive vehicle orbits—is critical to the operation of the pre-TPI routine called by P33 and P34. In particular, if the sign of ΔH_{CDH} is plus, indicating that the LM will be below the CSM after CDH, an elevation angle greater than 180 degrees will cause a 00611 alarm in P33 and P34. Such a situation is considered unlikely. Should it occur, however, the astronaut should key VERB 06 NOUN 55 ENTR—before final P33 computation—and follow with the appropriate load verb to change the elevation angle to the value that the CSM should use in a nominal TPI maneuver. (See paragraph 5.3.4.)

The other outputs of P32 are self-explanatory. The following facts, however, should be emphasized. The minutes part of outputs 5 and 6, DELTA T (CSI/CDH) and DELTA T (CDH/TPI), are displayed modulo 60. That is, if the minutes of either output 5 or output 6 are greater than 60, they are divided by 60 and the remainder is displayed. Thus, it is possible to see values in outputs 5 or 6 that appear to be less than 10 minutes, even though no alarm has been called. Simply remember that output 5 plus output 6 must equal the time interval between t_{IG}(CSI) and t_{IG}(TPI).

P32 calculates the CSI maneuver to be only along the x-axis of local vertical coordinates. If a plane change is desired at t_{IG}(CSI), the astronaut can call R36 (VERB 90 ENTR), and load the negative of the computed Y value for the LM into register R2 (the Y component) of the flashing VERB 06 NOUN 81 display.

5.3.2.3 Program Coordination

The LM crew verifies the LGC targeting solution by comparing it with the Abort Guidance System (AGS) solution and the CMC solution by voice link. The CMC and LM solutions should be nearly mirror images, i.e., opposite signs.

The criteria for selecting the correct solution are normally as follows:

1. If all three solutions agree (within mission-specified limits), use the LGC solution.
2. If the CMC and the AGS solutions agree, but the LGC solution disagrees, use the CMC solution.
3. If all three solutions disagree, use the CMC solution unless it is known to be, or suspected of being, unreliable.

5.3.2.4 Procedures for Correcting Alarm Conditions

When an alarm occurs and the astronaut wishes to change some input variable, he should key RSET and VERB 32 ENTR and use the appropriate load verb when the proper display comes up. In all cases, upon occurrence of an alarm display from P32, the first source of error to be considered should be bad input. The astronaut should recycle and check his input. Other possible sources of alarms are poor orbital configuration and bad estimates of state vectors in the LGC. If the estimates of state vectors contained in the LGC are believed to be bad, procedures should be followed to correct the situation. (See paragraph 4.3.1.) The following paragraphs assume good input conditions and good LGC state vector estimates.

All alarm codes are part of flashing display VERB 05 NOUN 09. Keying RSET and VERB 32 ENTR will recycle P32, allowing different inputs; VERB 34 ENTR will force the program to go to R00. A list of alarm codes and procedures that may allow the program to run to completion follows:

a. Alarm code 00600 may occur if the elevation angle line-of-sight from the active vehicle at TPI does not intersect the circle formed by the passive vehicle's radius at TPI.
b. Alarm code 00601 may occur if the post-CSI pericenter altitude is insufficient.
c. Alarm code 00602 may occur if the post-CDH pericenter altitude is insufficient.
d. Alarm code 00603 may occur if there is insufficient time between t_{IG}(CSI) and t_{IG}(CDH).
e. Alarm code 00604 may occur if there is insufficient time between t_{IG}(CDH) and t_{IG}(TPI).
f. Alarm code 00605 may occur if excessive iterations are occurring—without convergence.
g. Alarm code 00606 may occur if two successive iterations occur with a Δv greater than 1000 fps.

Alarm 00600 occurs if the active vehicle is so high relative to the passive vehicle at TPI, that it would be impossible to see the other vehicle with the given elevation angle. This alarm will not occur in P72, using the same inputs, so one solution is to make the other vehicle do the CSI maneuver. (If that is done, however, it is conceivable that alarm 00601 or 00602 will occur, and a ground-targeted maneuver will be required.) Increasing TPI time of ignition by one orbit, and increasing N by 1 or 2 may also help. One last possibility is to advance TPI time in 15-minute increments on successive cycles of P32. This violates the precondition that TPI be in the midpoint of darkness, but it may work.

Alarm codes 00601 and 00602 will generally occur when the active vehicle is forced to go into a lower orbit to catch up in phasing with the passive vehicle. The astronaut can (1) increase TPI time, (2) modify N, (3) have the other vehicle perform the CSI maneuver, or (4) request a phasing maneuver of ground.

Alarm code 00603 can always be avoided by using the 180-degree option (input 4 nonzero).

Should alarm 00604 occur, recycle and use the 180-degree option. Should the alarm occur again, increase the TPI time by one orbital period, retaining the 180-degree option.

Alarm 00605 is unlikely to occur. Should it occur, however, either recycle with a different N, usually increasing N by 1, or move the whole sequence up by one orbital period.

Alarm code 00606 may occur if Δt (CSI/TPI) is too small for a given configuration. Increasing TPI time should lower the Δv.

5.3.2.5 Restarts

P32 is restart protected.

5.3.3 P33, Constant Delta Altitude (CDH)—LGC

Constant Delta Altitude (CDH) is the second targeting program in the coelliptic sequence. The maneuver targeted by the program results in an active vehicle orbit that remains at a nearly constant radial distance from the passive vehicle orbit. The CDH targeting program is performed before the actual CDH maneuver time. The program recomputes the CDH maneuver data, using the same calculations as the CSI program, but using updated estimates of position and velocity resulting from navigation occurring after the CSI maneuver.

P33 targets for a CDH maneuver, using a CDH maneuver time—t_{IG}(CDH)—and a TPI maneuver time—t_{IG}(TPI)—and elevation angle (E) supplied by the astronaut at the beginning of P32.* In addition to targeting for CDH, P33 also uses a TPI subroutine to calculate a more precise TPI maneuver time. This allows the crew to schedule post-CDH activities.

The targeting of the CDH maneuver within P33 is separate from the determination of the TPI maneuver time. Whereas a CDH maneuver is calculated simply by equalizing the velocities in the z-direction of the local vertical coordinate system, the TPI subroutine takes the input t_{IG}(TPI) and uses it as an initial estimate in an iterative search for the precise time when the specified elevation angle occurs.

5.3.3.1 P33 Computational Sequence

Upon selection, P33 enables tracking and mark incorporation by setting the Track and Update flags. Then the LGC flashes VERB 06 NOUN 13, requesting the astronaut to supply a t_{IG}(CDH) for the program. Normally (unless subsequently changed by the astronaut), the time displayed will be the t_{IG}(CDH) computed and stored in P32. If the displayed time is acceptable, the astronaut records it and keys PRO causing the LGC to display flashing VERB 16 NOUN 45, requesting the astronaut to determine whether the next computation cycle will be a preliminary or final computation.

Responses to flashing VERB 16 NOUN 45 are VERB 32 ENTR for a preliminary computation and PRO for a final computation.

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*The crew will probably use the CDH maneuver time calculated by P32 if the LM performed the CSI maneuver. If the CM performed CSI, the crew should use the CDH time calculated by the CMC. Some alarm recovery procedures involve changing CDH maneuver time. (See paragraph 5.3.3.4.)

After an astronaut response to VERB 16 NOUN 45, the LGC prevents further mark incorporation, for the duration of the succeeding calculations, by resetting the Update flag. These calculations can be divided into two parts. The first involves the calculation of a maneuver that will make the active vehicle orbit coelliptic with the passive vehicle orbit. The second takes the resultant orbit, and determines the time when the desired E-angle occurs.

The first calculation is purely analytical; it calculates the velocity change necessary to make the active vehicle H-dot (rate of altitude change) equal to the passive vehicle orbital H-dot; that is, the rate of altitude change of the passive vehicle orbit at the intersection of the passive vehicle orbit and the line formed by the projection of the active vehicle's position vector into the passive vehicle's plane.

The second calculation uses the t_{IG}(TPI) input into P32 as an initial estimate in an iteration scheme to determine the exact time when the desired elevation angle will occur. If the calculation cannot be made, the LGC displays a VERB 05 NOUN 09 alarm, alarm code 00611. If no alarm occurs, or if PRO is keyed in response to the flashing VERB 05 NOUN 09 display, P33 proceeds to the next display, VERB 06 NOUN 75. Before flashing this display, however, P33 determines whether the astronaut has keyed PRO in response to VERB 16 NOUN 45. If the Final flag is set, he has keyed PRO; if reset, he has not, and P33 allows marks to be incorporated by setting the Update flag. The VERB 06 NOUN 75 display—ΔH_{CDH}, Δt (CDH/TPI), Δt (TPI/TPI)—follows immediately, and is followed in turn by VERB 06 NOUN 81, $\Delta \underline{v}$(LV). If the astronaut wishes to produce a node 90 deg after CDH, he can overwrite the contents of R2 of the NOUN 81 display with the value of minus Y-dot (LM) computed by R36, when the time displayed in NOUN 16 of R36 equals the time of CDH ignition.*

The next display is VERB 16 NOUN 45. If the last computation completed was preliminary, the astronaut normally waits until more marks are incorporated before requesting a final computation. If the last computation completed was final, another PRO response to VERB 16 NOUN 45 allows the program to exit via R00.

5.3.3.2 Input and Outputs

Table 5.3.3-I and Table 5.3.3-II summarize P33 displays. The following flag definitions also apply:

*R36 is initiated by keying in VERB 90 ENTR; Y-dot (LM) is displayed in R2 of NOUN 90 in R36.

TABLE 5.3.3-I

CONSTANT DELTA ALTITUDE (CDH) INPUT DISPLAYS (LM P33)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1*	Time of CDH ignition	TIG (CDH)	FL V06N13	R1 00xxx. hr R2 000xx. min R3 0xx. xx sec	This time is initially computed by P32. It should be changed (1) if CM did CSI, to CMC-computed t_{IG}(CDH) or (2) to recover from alarm conditions.
2*	Time of TPI ignition	TIG (TPI)	None	None	This time is also an input to P32. It is used as an initial estimate in the TPI subroutine called by P33 to calculate the actual time when E (input 3) occurs. Under certain conditions, it may be changed to help recover from alarm conditions. To call it up, key in VERB 06 NOUN 37 ENTR. (See paragraph 5.3.3.4.)
3*	Elevation angle	E	None	None	This angle is also an input to P32. It will be displayed in R2 of NOUN 55 if it is called up by the astronaut. It can be changed to recover from alarm conditions. (See paragraph 5.3.3.4.)

*These inputs are stored in the LGC at the time P33 is keyed in.

TABLE 5.3.3-II

CONSTANT DELTA ALTITUDE (CDH) OUTPUT DISPLAYS (LM P33) (SHEET 1 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1	Number of marks made since RR tracking mark counter was zeroed.	M	FL V16N45	R1 xxxxx.	VERB 32 ENTR starts computation process using latest update of state vector. PRO terminates mark process and completes final computation.
2	Time from ignition	TFI	FL V16N45	R2 xxBxx min,sec	Indicates time available for rendezvous navigation before CDH burn. Maximum reading is 59B59. Sign is minus before and plus after t_{IG}(CDH).
3	Middle gimbal angle at t_{IG}(CDH) if LM +X-axis is aligned with initial thrust direction.	MGA	FL V16N45	R3 xxx.xx deg or -00001 or -00002	a. Value is -00001 except during last pass through P33. b. Value is -00002 on last pass through P33 if IMU is not aligned. c. xxx.xx deg MGA displayed on last pass if IMU is aligned.
4	The altitude between the active and the passive vehicle orbits at t_{IG}(CDH). Sign is plus when the active vehicle is below the passive vehicle.	DELTA ALT (CDH)	FL V06N75	R1 xxxx.x n.mi.	Normal response to VERB 06 NOUN 75 is PRO.

TABLE 5.3.3-II

CONSTANT DELTA ALTITUDE (CDH) OUTPUT DISPLAYS (LM P33) (SHEET 2 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
5*	t_{IG}(TPI), as defined by P33, minus t_{IG}(CDH).	DELTA T(CDH/TPI)	FL V06N75	R2 xxBxx** min, sec	Computed in hours, minutes and seconds, of which only the minutes and seconds are displayed. This value can be negative; i.e., t_{IG} (TPI), as defined by P33, is before t_{IG}(CDH).
6*	t_{IG}(TPI), as defined by P33, minus t_{IG}(TPI), as defined by P32.	DELTA T(TPI/TPI)	FL V06N75	R3 xxBxx* min, sec	If a PRO response was received to alarm display VERB 05 NOUN 09, R3 will be zero, and R2 will be calculated using t_{IG}(TPI) as defined by P32.
7	Components of impulsive velocity change for CDH, in local-vertical coordinates.	DELTA V(LV)	FL V06N81	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	A plane change can be made by keying in R36, VERB 90 ENTR, including the negative of the $\dot{Y}$(LM) result in the Y component of the DELTA V(LV).

*t_{IG}(TPI) computed by P33 can be displayed by keying in VERB 06 NOUN 37 ENTR.

**R2 and R3 displayed values are modulo one hour, with the exception that R2 is limited to 59B59 if it is negative.

a. If Track flag is set, tracking is allowed. If reset, it is not allowed. If Update flag is set, the state vector may be updated from navigation marks. If it is reset, updating from marks is not possible.

b. REFSMMAT flag set indicates that the IMU alignment is known; reset, it is unknown.

c. Final flag set indicates the astronaut has keyed PRO in response to VERB 16 NOUN 45. Reset means he has not.

> NOTE.—The setting and resetting of the Track and Update flags refer to P20 functions. See paragraph 4.3.1 for a description of P20—targeting program coordination.

Table 5.3.3-II lists P33 output. Outputs 1, 2, and 3 display the status of the Rendezvous Navigation Program (P20) running in the background. R1 shows the number of marks incorporated in P20. R2 shows how much time is left before CDH ignition to take marks and perform the final P33 computation. R3 indicates whether the LGC will accept marks or not. If R3 equals -00001, final computations have not been made by the LGC, and marks can be incorporated during any flashing display, except an alarm display. To terminate the marking process, and use the current estimate of the state vectors in the computer, the crew should key PRO in response to the VERB 16 NOUN 45 display.

After PRO is keyed, no more marks will be incorporated into the state vector until reselection of a targeting program; the LGC will calculate the maneuver parameters for a final time, display the other outputs, and then redisplay VERB 16 NOUN 45. After the final computation, the LGC indicates the IMU status in R3 of NOUN 45. If the alignment is unknown, R3 equals -00002. Otherwise, R3 contains the middle gimbal angle at t_{IG}(CDH). Once PRO has been keyed as a response to VERB 16 NOUN 45, keying PRO again terminates the program via Routine 00. Keying VERB 32 ENTR is undesirable at this point because no parameters will change (that is, no marks will be accepted or incorporated).

Output 4 is the radial distance, at CDH, between the active vehicle and the passive vehicle orbit just above or below it. Output 4 is critical to recovery from alarm conditions. (See paragraph 5.3.3.4.)

Output 5 is Δt(CDH/TPI). In calculating the correct time of ignition of TPI, P33 first calculates the CDH maneuver parameters, and then extrapolates the post-CDH orbit. Time of TPI ignition is then calculated on the basis of that orbit. Using the Orbital Integration Routine, the post-CDH state can be extrapolated backwards in time, before CDH, as well as forward. It is conceivable that the desired elevation

angle might exist only before CDH, based on the post-CDH orbit. That is, if it were possible for the active vehicle to have been on the post-CDH orbit prior to CDH, then the desired elevation angle would have existed at some time prior to CDH. Should this be the case, the computer will not be aware of the time difference, and will accept the indicated solution as a valid one. The astronaut can detect the occurrence of such a situation by observing output 5. A negative output 5 indicates that P33 calculated TPI as coming before CDH. One of the conditions that P32 calculations must satisfy is that the time interval between CDH and TPI—Δt(CDH/TPI)—be greater than 10 minutes to allow time for rendezvous navigation after CDH. Output 5 of P33, however, can be negative, allowing no time for rendezvous navigation after CDH. Further, P33 accepts a negative solution as a valid solution. P33 also accepts an output 5 value of less than 10 minutes as a valid solution—a situation that would not provide sufficient navigation time. These situations might occur if CSI were poorly targeted, because of bad state vector estimates, or if CSI were poorly executed. In any case, the crew should carry out the CDH maneuver as targeted, select P34 with the time option (E equals 00000), and set the time of ignition for TPI in accordance with mission procedures.

Output 6 is Δt(TPI/TPI), the difference between the t_{IG}(TPI) input to P33 and that calculated by P33. The minutes part of output 6, and positive values of output 5, are displayed modulo 60. Negative values of output 5 are limited to a display of 59B59. A large difference between the input t_{IG}(TPI) and the calculated t_{IG}(TPI) usually means that navigation after CSI has considerably changed the LGC estimate of the vehicle state vectors. This large difference is likely to occur if CSI were either poorly targeted or poorly executed.

5.3.3.3 Program Coordination

P33 makes a preliminary calculation fairly soon after CSI to determine the maneuver characteristics; the program makes a final computation (crew-determined and in accordance with mission procedures) approximately 9 to 12 minutes before t_{IG}(CDH). P33 can run by itself (in which case the ISS need not be operating) or it can run in conjunction with P20 (in which case marks can be incorporated during any flashing display—except an alarm display—until final computation is initiated by the astronaut by a PRO response to VERB 16 NOUN 45). The minimum time to allow for a final computation is 3 minutes.

Optimum targeting in P33 depends on relatively error-free estimates of the state vectors of the two vehicles with respect to each other. Ordinarily, there is ample time between CSI and CDH for P20 to reduce state vector errors. (Refer also to paragraph 4.3.1 for coordination between P20 and the targeting programs.)

The LM crew verifies the LGC targeting solution by comparing it with the Abort Guidance System (AGS) solution, the CMC solution, and the ground (MSFN) solution by voice link. The CMC and LGC solutions should be nearly mirror images, i.e., opposite signs.

5.3.3.4 Alarms

Alarm code 00611, the only alarm that can occur during P33, indicates to the crew that the TPI subroutine is unable to calculate a time of occurrence for the desired elevation angle. Recommended procedures, in case of occurrence of this alarm, are detailed in paragraph 5.2.3.4 for the CSM and also apply to the LM. Refer also to Figure 5.2.3-2 and Table 5.2.3-III.

5.3.3.5 Restarts

A restart that occurs during the operation of P33 will only cause a time loss (the maximum time loss is just less than the time required for final computation), not a loss of validity in the solution.

5.3.4 P34, Transfer-phase Initiation (TPI)—LGC

P34 targets for the transfer-phase initiation maneuver (TPI). When used as part of the concentric flight plan (see subsections 5.1 and 5.2), the transfer phase follows the coelliptic sequence (CSI and CDH) and begins with the characteristics described in paragraph 5.2.4. When used in the nominal rendezvous (see note below), P34 initiates the direct rendezvous sequence and computes the parameters necessary to put the active vehicle on an intercept trajectory with the passive vehicle. P34 accomplishes this by determining the impulsive velocity change required such that the active vehicle will be on a trajectory that intercepts the passive vehicle orbit at a particular point and in a specified time of flight.

> NOTE.—The nominal rendezvous maneuver sequence (direct rendezvous) uses only P34 and P35 to effect rendezvous. When phasing between the active and passive vehicles does not allow use of direct rendezvous, the concentric flight plan sequence, and the plane-change maneuver are available as backup.

Under crew option, the program can determine the time at which the desired elevation angle occurs using the input TPI time as an initial estimate and iterating to find the actual time. The iteration assumes that the vehicle is moving at an approximately constant angular rate.

To maintain proper lighting conditions at the final phase, however, the crew can choose to bypass the elevation angle option and specify the TPI time directly. (Refer to paragraph 5.3.4.3, step 2.) For direct rendezvous, the crew loads a TPI ignition time that results in an elevation angle of approximately 27 deg. This ensures standard terminal conditions after the TPI maneuver. Since the active and passive vehicle orbits are not necessarily coelliptic in direct rendezvous before TPI, however, the direction of the thrust vector will not be along the LM–CSM LOS.

Like the other targeting programs, P34 interfaces with P20, running in the background, to improve the estimate of the state vectors, and with P40, P41, or P42, the thrusting programs, to carry out the maneuver targeted by P34. The crew can request preliminary estimates of the TPI maneuver during P34 execution before navigation is completed. Incorporation of navigation marks continues until the crew initiates the final computation.

5.3.4.1 P34 Computations

P34 is divided into two computation phases, the first of which computes the input to the second. The first phase can be performed in two different ways. Either it accepts a desired elevation angle and iterates to determine the time when that angle occurs, or it accepts a time and calculates the elevation angle occurring at that time. The second phase takes the calculated (or desired) E-angle and the calculated (or desired) time, and the desired central angle of transfer (CENTANG) from t_{IG}(TPI) to intercept time, t_{IG}(TPF), and calculates a Lambert maneuver designed to effect intercept. The target vector is determined either conically, or with precision offsets.

5.3.4.2 Discussion of P34 Inputs and Outputs

Tables 5.3.4-I and 5.3.4-II describe P34 crew inputs and P34-computed output. The tables are to be used in conjunction with paragraph 5.3.4.3 to give the reader an overall view of P34 sequencing and procedures. This paragraph briefly discusses the inputs and outputs in preparation for paragraph 5.3.4.3. In addition, the following flag definitions also apply:

1. Track and Update flags refer to P20. If the Track flag is set, tracking is allowed. If reset, tracking is not allowed. If the Update flag is set, marks will be incorporated; if it is reset, marks can be taken, but will not be incorporated.
2. Final flag set means a PRO response to a flashing VERB 16 NOUN 45 display has been received; reset, a PRO response has not been received.

Input 1, t_{IG}(TPI), is ordinarily retained as displayed. This value for TPI ignition is usually the same as the one computed in P33. If everything has gone well, the input t_{IG}(TPI) should be close to the time when the actual elevation angle coincides with the desired elevation angle (input 3).

Input 2, NN, governs which method of calculation the program will use in the second computation phase. If NN equals 00000, the program calculates a conic approximation of the correct TPI maneuver. In the lunar-gravitational sphere, the accuracy of this method is equivalent to that of target offsetting. The advantage of the conic method is its speed in obtaining an answer. For earth-orbital rendezvous, the precision offset method (NN equals 00002) is recommended for a correct answer because of oblateness effects, in spite of the longer calculation time. (Refer to Table 5.3.4-I.)

TABLE 5.3.4-I

TRANSFER-PHASE INITIATION (LM P34) CREW-SPECIFIED INPUT DISPLAYS

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1	TPI time of ignition	TIG(TPI)	FL V06N37	R1 00xxx. hr R2 000xx. min R3 0xx. xx sec	Initially flashes the value computed by P33 (unless subsequently changed by the astronaut). If the elevation angle is to be calculated, input 1 will be used as an initial estimate by P34 to locate the time when the elevation angle coincides with the desired E (input 3).
2	Conic–precision switch; if positive, number of offsets to be used in Lambert targeting.	NN	FL V06N55	R1 xxxxx.	00000 – The recommended value for lunar orbital activities, the very fast conic integration will be used to calculate the TPI maneuver. +00002 – Recommended for earth orbit activities to account for oblateness effects. Any positive number will cause the program to use that number of precision offsets.
3	E-option–time-option switch; if nonzero, desired E angle	E	FL V06N55	R2 xxx.xx deg	00000 – Program will accept input 1 as desired t_{IG}(TPI), and calculate a TPI maneuver for that time. Nonzero – P34 uses input 1 as an initial estimate in an attempt to find the time of occurrence of given elevation angle.
4	Central angle through which the passive vehicle must pass from t_{IG}(TPI) to intercept.	CENTANG	FL V06N55	R3 xxx.xx deg	Set according to mission procedures.

TABLE 5.3.4-II

TRANSFER-PHASE INITIATION (LM P34) PROGRAM-CALCULATED DISPLAYS

(SHEET 1 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1	Number of marks made since mark counter was zeroed.	M	FL V16N45	R1 xxxxx.	VERB 32 ENTR starts computation process using latest update of state vectors. PRO terminates mark incorporation and completes final computation.
2	Time from Ignition	TFI	FL V16N45	R2 xxBxx min,sec maximum: 59 min, 59 sec	Indicates time available for rendezvous navigation before TPI burn.
3	Middle Gimbal Angle at t_{IG}(TPI) if LM +X-axis is aligned with initial thrust direction	MGA	FL V16N45	R3 xxx.xx deg or -00001 or -00002	-00001 — Indicates final computation has not been requested. -00002 — Indicates final computation requested but IMU not aligned. +xxx.xx — Middle gimbal angle at t_{IG}(TPI) if LM +X-axis is aligned with initial thrust direction.
	If the astronaut requested the elevation angle be calculated, outputs 4, 5 and 6 (FL V06N55) will follow outputs 1, 2 and 3, and then output 8 will follow. Otherwise output 7 (FL V06N37) will follow 1, 2, and 3.				
4	Number of target offsets	NN	FL V06N55	R1 xxxxx.	Displays calculation method specified by the astronaut.
5	Elevation angle. (See input 3 for definition)	E	FL V06N55	R2 xxx.xx deg	Displays the calculated elevation angle for the given t_{IG}(TPI).

TABLE 5.3.4-II

TRANSFER-PHASE INITIATION (LM P34) PROGRAM-CALCULATED DISPLAYS

(SHEET 2 OF 2)

Output	Identification	Display Mnemonic	DSKY	Register	Comments
6	Orbital central angle of the passive vehicle during transfer from t_{IG}(TPI) to intercept.	CENTANG	FL V06N55	R3 xxx.xx deg	Displays value specified by the astronaut in input 4.
7	Calculated time of ignition for TPI.	TIG(TPI)	FL V06N37	R1 00xxx. hrs R2 000xx. min R3 0xx.xx sec	Calculated t_{IG}(TPI) for given elevation angle.
8	Perifocus altitude.	PER ALT	FL V06N58	R1 xxxx.x n.mi.	Altitude above launch pad radius for the earth, or altitude above the latest landing site, for the moon.
9	Impulsive velocity change for TPI	ΔV(TPI)	FL V06N58	R2 xxxx.x fps	P34 and P35 burns are Lambert maneuvers.
10	Impulsive velocity change for TPF	ΔV(TPF)	FL V06N58	R3 xxxx.x fps	
11	Impulsive velocity change vector in local-vertical coordinates	ΔV(LV)	FL V06N81	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	Crew has the option at this time to redefine the Δv(LV) components for the subsequent thrusting maneuver. NOTE.—To make out-of-plane corrections, key V90E (R36) and overwrite R2 with minus Y-dot (LM) (R2 of the NOUN 90 R36 display).
12	Impulsive velocity change vector in LOS coordinates	ΔV(LOS)	V06N59	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	Available upon request by crew.

Input 3, E, governs which method of calculation the program uses in the first computation phase. If E equals 00000, the program calculates a maneuver appropriate to the input t_{IG}(TPI). If E does not equal 00000, the program will accept the input number as an angle, to the nearest 0.01 degree, and use the input TPI ignition time (input 1) as an initial estimate for the TPI subroutine.

Input 4, CENTANG, indicates the orbital central angle through which the passive vehicle must pass between t_{IG}(TPI) and intercept. Implicit in CENTANG is a target vector and a transfer time, which the Lambert targeting routine uses as input.

Table 5.3.4-II lists P34 output. VERB 16 NOUN 45 (outputs 1 through 3) show the status of P20 in the LGC. R1 shows the number of marks made since the RR tracking mark counter was zeroed. The rendezvous mark counter is zeroed (1) upon selection of P20, (2) after each thrusting maneuver, (3) when the W-matrix is reinitialized, (4) during P76 or P77 execution, and (5) upon a PRO response to FLV16 N80 display in R24. R2 shows how much time is left to take marks and perform the final P34 computation before ignition. R3 indicates whether the LGC will accept marks. If R3 equals -00001, final computations have not been made by the LGC, and marks can be incorporated during some flashing displays. If the astronaut wishes to terminate the marking process and use the current estimate of the state vectors in the LGC for a final P34 solution, he should key PRO in response to a VERB 16 NOUN 45 display. After PRO, no more marks will be incorporated in the LGC state vector. The computer will calculate the maneuver parameters for a final time, display the other outputs, and then redisplay VERB 16 NOUN 45. After the final computation, the IMU status is displayed in R3. If the alignment is unknown, R3 equals -00002; otherwise, R3 shows the middle gimbal angle at t_{IG}(TPI) as a positive number. A second PRO response to VERB 16 NOUN 45 terminates the program via Routine 00. The astronaut should not attempt to recycle (by keying in VERB 32 ENTR) at this point, because no parameters will change; that is, no marks will be incorporated.

Depending on the option used, either a VERB 06 NOUN 55 or a VERB 06 NOUN 37 will be displayed after all but the final VERB 16 NOUN 45. If the elevation angle option is chosen, the program will compute E for the specified t_{IG}(TPI), and display it as R2 (output 5) in a VERB 06 NOUN 55 display. Registers R1 and R3 will be identical with inputs 2 and 4 supplied by the astronaut. If the time option is chosen, output 7, the computed t_{IG}(TPI), will be displayed in a VERB 06 NOUN 37.

After either the NOUN 55 or the NOUN 37 display, the program calculates the velocity change required for the TPI maneuver. When the thrust vector is calculated, the

program displays a VERB 06 NOUN 58, containing outputs 8, 9 and 10 in R1, R2 and R3, respectively. Refer to Table 5.3.4-II for an explanation of these outputs, which represent the magnitudes of the initial and final maneuvers of the transfer phase. Outputs 11 and 12 show the thrust vector displayed first in the local vertical coordinates, at t_{IG}(TPI), and then, optionally, in LOS coordinates. For a detailed description of the local vertical coordinate system, refer to paragraph 5.1.5.

As was mentioned above, VERB 16 NOUN 45 is displayed again after the final computation, before the program terminates, and R3 contains either -00002 or the positive value of the middle gimbal angle at TPI ignition time.

5.3.4.3 P34 Procedures

1. The astronaut calls P34 by keying VERB 37 ENTR 34 ENTR. Upon entry, P34 enables tracking and mark incorporation (in P20) by setting the Track and Update flags. The DSKY then displays the t_{IG}(TPI) as follows:

   FL V06 N37

R1	00xxx.	hr
R2	000xx.	min
R3	0xx. xx	sec

   Key PRO to accept the displayed t_{IG}(TPI). To load desired TPI time, key VERB 25 ENTR, load time, and key PRO.

   NOTE 1.—P34 requires that the initial value of t_{IG}(TPI) be within 30 min of the actual TPI time.

   NOTE 2.—The time displayed in NOUN 37 will most likely be that computed by P33, if in the concentric flight plan. If a 00611 alarm generated by P33 was bypassed, the time displayed will be that input by the astronaut to P32—unless subsequently changed by him.

2. After appropriate crew response to the first P34 display, the DSKY flashes the following display, allowing the astronaut to exercise the two choices available in P34—the conic or precision-offset targeting choice in R1 and the elevation angle or time choice in R2:

FL VERB 06 NOUN 55

R1	NN	xxxxx.
R2	E	xxx.xx deg
R3	CENTANG	xxx.xx deg

Conic/Precision-offset Targeting Choice (R1)

a. To specify Kepler conic integration, ensure NN equals zero (initial display is +00000).

b. To specify precision integration, key VERB 21 ENTR and load R1 with a positive number.

NOTE.—If a non-zero positive number is loaded, the program performs that number of offsets.

Elevation Angle/Time Choice (R2)

a. To request that E be calculated based on the previous display of t_{IG}(TPI), ensure R2 contains all zeros (initial display is +000.00 deg).

NOTE.—For direct rendezvous, the crew loads a t_{IG}(TPI) that results in an elevation angle of approximately 27 deg. This ensures standard terminal conditions after the TPI maneuver. Since the active and passive vehicle orbits are not necessarily coelliptic before TPI, however, the TPI Δv will not be along the LM–CSM LOS.

b. To request that t_{IG}(TPI) be calculated based on a given elevation angle, key VERB 22 ENTR, and load desired elevation angle value.

NOTE.—In the concentric flight plan—in which the active and passive vehicle orbits are nominally coelliptic before TPI—an elevation angle of approximately 27 deg ensures a TPI Δv along the LM–CSM LOS, as well as standard terminal conditions after the TPI maneuver.

CENTANG (R3)

CENTANG is the orbital central angle of the passive vehicle during transfer from t_{IG}(TPI) to the time of intercept. (The nominal value is 130 deg.) To change the displayed value, key VERB 23 ENTR and load desired value.

Key PRO.

NOTE.—The astronaut can terminate P34 at this point by keying VERB 34 ENTR. The LGC will respond with a flashing VERB 37 allowing him to choose a new program.

POSSIBLE ALARM. If the astronaut chooses the time option, keys PRO, and the LGC cannot find a t_{IG}(TPI) for the given elevation angle, the DSKY flashes the following display, and the LGC illuminates the PROG light.

NOTE.—An alarm appears in both R1 and R3 of NOUN 09 if it is the only alarm; in both R2 and R3 if it is the second alarm; and only in R3 if it is the third alarm. R3 always contains the latest alarm. Depressing RSET clears R1 and R2, but does not clear R3.

FL VERB 05 NOUN 09

$$\left.\begin{array}{l}\text{R1}\\ \text{R2}\\ \text{R3}\end{array}\right\}\ 00611$$

Key RSET and PRO. The program returns to the initial VERB 06 NOUN 37 display of t_{IG}(TPI) (step 1).

3. Upon astronaut's PRO, P34 displays the following P20—relevant data.

FL VERB 16 NOUN 45

R1	xxxxx.	M
R2	xxBxx	min, sec TFI
R3	xxx.xx	deg MGA

R1 displays the number of marks incorporated since the mark counter was zeroed. R2 displays the time from TPI ignition. The sign is minus before ignition, and plus after.

R3 displays the MGA at t_{IG}(TPI).

NOTE.—When displayed at any time—other than the last pass through P34—R3 contains -00001.

To obtain preliminary solution and to continue marks (if P20 running in the background) key VERB 32 ENTR.

NOTE.—VERB 32 ENTR response continues program, but does not set Final flag. Used when another pass is desired.

(1) Go to step 5 if elevation angle is to be calculated.

(2) Go to step 4 if t_{IG}(TPI) is to be calculated (unless alarm occurs).

To obtain final solution and to terminate marks, key PRO.

NOTE.—PRO response sets Final flag, indicating that this is the last pass through P34 computations.

(1) If elevation angle to be calculated, go to step 5.

(2) If t_{IG}(TPI) to be calculated, go to step 4.

. To terminate P34, key VERB 34 ENTR, go to step 9.

4. If the astronaut chooses the time option, by loading the desired elevation angle into R2 of NOUN 55, and the LGC uses the TPI subroutine to sucessfully calculate a time of occurrence for that given elevation angle, P34 displays the calculated TPI time as follows:

FL VERB 06 NOUN 37

R1	00xxx.	hr
R2	000xx.	min
R3	0xx. xx	sec

Record the t_{IG}(TPI). Key PRO. Go to step 6.

5. If the astronaut chooses the elevation angle option by loading +00000 in R2 of NOUN 55, P34 will take the initial input TPI ignition time, compute the elevation angle occurring at that time, and display the result in R2 of the following:

FL VERB 06 NOUN 55

R1	xxxxx.	NN
R2	xxx.xx	deg E
R3	xxx.xx	deg CENTANG

Record displayed data. Key PRO.

6. After either the NOUN 37 or the NOUN 55 display, P34 calculates the velocity change required for the TPI maneuver and displays it as follows:

FL VERB 06 NOUN 58

R1	xxxx.x	n.mi. Hp
R2	xxxx.x	fps Δv(TPI)
R3	xxxx.x	fps Δv(TPF)

R1 displays altitude of perifocus above launch pad radius in earth orbit; above lunar radius at most recently defined landing site in lunar orbit.

R2 displays impulsive ΔV required to place the active vehicle on an intercept trajectory with the passive vehicle orbit.

R3 displays impulsive Δv required to match active and passive vehicle orbits at intercept time.

Record displayed data. Key PRO.

OPTIONAL DISPLAY.— To verify that the central angle of the active vehicle is not within 165 deg to 195 deg key:

VERB 06 NOUN 52 ENTR

R1	xxx.xx	deg	ACTCENT (active vehicle central angle)
R2	Blank		
R3	Blank		

Key KEY REL.

NOTE.—Normally ACTCENT is approximately 145 deg; an ACTCENT within 165 to 195 deg is very unlikely. Should it occur, however, the astronaut must exit P34, and reassess the input targeting parameters based on Δv and expected maneuver. He can reenter P34 in approximately 10 to 12 min, since ACTCENT will be closing.

7. P34 displays the impulsive velocity change in local-vertical coordinates as follows:

FL VERB 06 NOUN 81

R1	xxxx.x	fps X
R2	xxxx.x	fps Y
R3	xxxx.x	fps Z

To accept displayed data, record data. Key PRO.

To load new data, key VERB 25 ENTR, load desired values. Key PRO.

NOTE.—The astronaut can overwrite R2 with minus Y-dot(LM) from R36 to make out-of-plane corrections. P34 then recomputes the target vector accordingly.

OPTIONAL DISPLAY.—The astronaut can get a display of the required velocity change in LOS coordinates by keying the following:

VERB 06 NOUN 59 ENTR

R1	xxxx.x	fps X (LOS 1)
R2	xxxx.x	fps Y (LOS 2)
R3	xxxx.x	fps Z (LOS 3)

Record data. Key PRO.

NOTE.—Δv(LOS) are components of required impulsive change in velocity vector in an orthogonal coordinate system oriented along LM-to-CSM LOS.

LOS 1—is component along unit I

LOS 2—is component along unit (H×I) xI

LOS 3—is component along unit (H×I)

where,

I = unit vector along LOS to CSM

H = unit vector along LM orbital momentum vector.

8.

FL VERB 16 NOUN 45

R1	xxxxx.	M
R2	xxBxx	min, sec TFI
R3	xxx.xx	deg MGA

R1 is number of marks made since mark counter was zeroed.

R2 is time from t_{IG}(TPI); minus before, plus after.

R3 is the middle gimbal angle at t_{IG}(TPI) if LM +X-axis is aligned with initial thrust direction. Sign is +, except:

a. When displayed at any time other than last pass through program value is -00001.

b. On last pass, when IMU is not aligned, value is -00002.

NOTE.—If the last computation was preliminary, i.e., VERB 32 ENTR was keyed to first FL VERB 16 NOUN 45 display, astronaut will probably wait until a few more marks are incorporated before requesting a final computation. If last computation was final, i.e., PRO was keyed to first FL VERB 16 NOUN 45, keying PRO a second time allows P34 to exit via R00.

. To obtain another preliminary solution, key VERB 32 ENTR.

a. If LGC is to calculate E, return to step 5.

b. If LGC is to calculate t_{IG}(TPI) return to step 4.

. To terminate marks, key PRO.

a. If not final pass, to calculate E return to step 5.

b. If not final pass, to calculate t_{IG}(TPI) return to step 4.

c. If final pass (see note, above) go to step 9.

.To terminate program, key VERB 34 ENTR, go to step 9.

9. FL VERB 37

Key xx ENTR.
Exit P34.

5.3.4.4 Program Coordination

Like all the rendezvous targeting programs, P34 can be used in conjunction with P20, which runs in the background. Although P20 requires that the ISS be running and aligned, P34 does not. Marks are incorporated, however, only during the initial NOUN 55 and NOUN 37 displays and during NOUN 45 and NOUN 81 displays preceding the request for final computation (PRO to flashing VERB 16 NOUN 45).

5.3.4.5 Program Limitations

Under certain conditions, such as a small ΔH_{CDH}, the program may not be able to compute the time of occurrence, t_{IG}(TPI), for the given elevation angle. This will cause a 00611 alarm code to be stored in VERB 05 NOUN 09. If this alarm occurs, the procedures outlined in paragraph 5.3.4.6 should be followed. The elevation-angle option will always produce a solution for rendezvous.

5.3.4.6 Alarms

Alarm 00611 is the only alarm code likely to occur during P34. The circumstances under which alarm 00611 might occur are described in paragraph 5.2.3.4 for the CM, and are similar to those for the LM. Unless CDH is poorly performed, this alarm should occur during P33 when the astronaut has more time to search for a solution. In a time-critical situation like the period between CDH and TPI, the iteration process used to find t_{IG}(TPI) is usually too lengthy to be used more than once. Therefore, if a 00611 alarm should occur in P34, it is recommended that the astronaut recycle (by keying in PRO), request that the elevation angle be calculated—based on previous display of t_{IG}(TPI), (input 3, E equals 00000), and leave the other inputs unchanged.

5.3.4.7 Restarts

P34 is protected against restarts. If one should occur during P34 operation, no loss of accuracy, but a loss of time—equal at most to the time required for a final computation—would occur.

5.3.5 P35, Transfer-phase Midcourse (TPM)—LGC

P35 calculates the required velocity change and other initial conditions required by the LGC for LM execution of the next midcourse correction of the transfer phase for a LM-active rendezvous. All the data P35 needs for its calculations are available in the LGC at the time P35 is selected by the astronaut. These data are as follows:

a. Active and passive vehicle state vectors updated by P20

b. Time of intercept calculated by P34

c. Time of ignition, defined as:

   Current time (i.e., time of response to FL V16 N45 display) + A where A is a time increment either pad-loaded, crew-loaded, or loaded via P27 uplink.

d. NN, the conic–precision offset target switch, specified during P34 in R1 of NOUN 55.

Given these parameters, P35 targets a midcourse correction using the Lambert routine. It computes the required Lambert target vector and transfer time, and displays the required impulsive velocity change in local vertical coordinates—and optionally in LOS coordinates. P35 also allows the astronaut to monitor the progress of P20 by flashing the standard VERB 16 NOUN 45 display described in paragraph 5.3.4.

> NOTE.—Once the parameters required for maneuver calculation have been completely specified, the LGC computes and stores the value of the active vehicle central angle of transfer. The astronaut can get a display of this value by keying VERB 06 NOUN 52 ENTR. (See paragraph 5.3.5.3.)

Like all the other rendezvous targeting programs, P35 interfaces with P20 for navigation and with P40, P41, or P42, the thrusting programs, to accomplish the maneuvers. RR marks are taken automatically and incorporated during any flashing display before final computation is requested by a PRO response to VERB 16 NOUN 45. No alarms are expected during P35.

5.3.5.1 Options

P35 provides one choice to the astronaut. He can decide whether he wishes a preliminary or a final computation of the midcourse correction velocity change. This decision is based on mission procedures and the status of P20 navigation, i.e., whether sufficient marks have been incorporated or not.

5.3.5.2 P35 Computational Sequence

During the P35 computational sequence, required data are obtained from various computer locations; the target vector is then calculated, using either conic integration or the precision offset method, as specified by the astronaut in R1 of NOUN 55. (Refer to paragraph 5.3.4.) Tables 5.3.5-I and 5.3.5-II show P35 required input data and computed output displays, respectively.

Upon selection, P35 enables tracking and mark incorporation by setting the Track and Update flags. The LGC then flashes VERB 16 NOUN 45. R2 of this display, showing the time from ignition (TFI), displays a positive number the first time VERB 16 NOUN 45 comes up. The time displayed is actually the time from ignition of the last maneuver (time from cutoff if P40 or P42 was used) because the registers containing t_{IG}(TPM) are not loaded until the astronaut responds to VERB 16 NOUN 45. This allows the astronaut to schedule the midcourse maneuvers according to mission planning.

After a PRO or VERB 32 ENTR response to the VERB 16 NOUN 45 display, a pad-loaded or uplinked time increment, A, is added to the time when the response was made, giving the TPM ignition time (even if the current cycle is a preliminary computation). The LGC then uses the time of intercept computed in P34 to extrapolate the target vector. If the astronaut has specified precision offsets during P34 (NN was nonzero in P34), P35 uses precision offsets to compute the target vector. If the astronaut has specified conic integration in P34 (NN zero in P34), P35 computes the target vector conically.

After the target vector and the corresponding velocity change have been computed, P35 displays the velocity change in local vertical coordinates via VERB 06 NOUN 81. This display allows the astronaut to overwrite R2 with minus Y-dot (LM) computed by R36. If he does so, P35 recomputes the target vector accordingly. Optionally, he can get a display of the velocity change in LOS coordinates by keying VERB 06 NOUN 59 ENTR.

The final display, common to all targeting programs, is VERB 16 NOUN 45. Keying PRO to this display allows P35 to exit via R00.

5.3.5.3 Restrictions and Limitations

If input 4, CENTANG, to P34 was greater than 180 deg, the transfer angle from position at t_{IG}(TPM) to the target vector (displayed by keying VERB 06 NOUN 52 ENTR) might be within 165 to 195 deg. If it is, P35 will rotate the target vector

TABLE 5. 3. 5-I

TRANSFER-PHASE MIDCOURSE (LM P35)
PROGRAM-REQUIRED DATA

Required Data	Identification	Data Source (No inputs are displayed)	Comments
1*	Time of midcourse correction	TIG (TPM) is the time when the current recycle or final computation was requested, plus a pad-loaded or uplinked delay interval, A. A is nominally three minutes.	Given that t_{IG}(TPM) changes with each recycle or final computation (or restart, if one occurs between the request for a recycle or final computation and the corresponding solution), one can expect the calculated maneuver to change somewhat with each computation.
2*	Time of intercept	Calculated by P34 from CENTANG.	
3*	Conic–Precision-offset switch, NN.	If P34 was requested to do conic targeting (R1 of NOUN 55 = 00000), P35 will do the same. If P34 did a certain number of precision offsets, P35 will do the same number.	

*No actual input is required.

TABLE 5.3.5-II

TRANSFER-PHASE MIDCOURSE (LM P35) PROGRAM-CALCULATED DISPLAYS

No.	Identification	Mnemonic	DSKY	Register	Comments
1	Number of marks made since mark counter was zeroed.	M +	FL V16N45 +	R1 xxxxx. +	A VERB 32 ENTR response to a flashing VERB 16 NOUN 45 display will recycle for a preliminary computation. An initial PRO response will halt incorporation of marks and allow final computation. If it is decided that the final computation cannot be used, a VERB 32 ENTR response will allow a final comp with a slightly later t_{IG}(TPM). Once an initial PRO has been keyed in response to a flashing VERB 16 NOUN 45 display, no more marks will be incorporated until Update flag is once again set—for instance by reselecting P35.
2	Time from ignition	TFI	FL V16N45	R2 xxBxx min,sec	Initially counting up from last ignition, or cutoff, if P40 or P42 used.
3	Middle Gimbal Angle at t_{IG}(TPM) if LM +X Axis is aligned with initial thrust direction.	MGA	FL V16N45	R3 -00001 or -00002 or +xxx.xx deg	-00001 — Value displayed except during last pass through P35. -00002 — Value displayed during last pass if IMU not aligned. +xxx.xx deg — Middle gimbal angle at t_{IG}(TPM).
4	Impulsive change in velocity, in local-vertical coordinates.	DELTA V(LV)	FL V06N81	R1 xxxx.x fps X R2 xxxx.x fps Y R3 xxxx.x fps Z	The Y component can be overwritten with minus Y-dot (LM), calculated by R36 to make out-of-plane corrections.

into the plane of the active vehicle, resulting in the loss of any out-of-plane correction. If the transfer angle is within 165 to 195 deg, it is recommended that the maneuver be recalculated about 12 minutes later, in the lunar sphere—since a delay allows the transfer angle to become less than 165 deg—to eliminate the loss of any out-of-plane correction.

5.3.5.4 Restarts

If a restart occurs during the calculation of the TPM maneuver (after a response to VERB 16 NOUN 45 but before the next display), P35 starts again just after the VERB 16 NOUN 45 display. Since the time increment, A, is added to the current time after the restart protection point in the program, the maneuver will be targeted for a time slightly later than A plus the time of restart occurrence.

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5.3.6—5.3.9 P72–P75, LGC Targeting of CSM-active Maneuvers

The LGC programs for targeting a CSM-active maneuver are P72–P75; they are identical to LGC P32–P35 except that the choice of active vehicle for targeting computations is the CM and the passive vehicle is the LM. The LGC uses P72–P75 to target CSM-active maneuvers only if the CM optics and VHF range sensors are malfunctioning. In that instance, after an appropriate P7x program is performed by the LM, the thrusting parameters are voice-linked to the CSM for use in the CMC External-Δv Program (P30).

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5.3.10 P76, CM Target-Δv—LGC

P76 notifies the LGC that the CM has changed its orbit by executing a thrusting maneuver. This notification is accomplished by updating the LGC-resident CM state vector to reflect the thrusting parameters for the CM maneuver.

5.3.10.1 Inputs and Outputs

After each CM maneuver, the Lunar Module Pilot (LMP), using P76, updates the CM state vector by entering the CM thrusting parameters supplied by voice-link from the CM crew.

a) Δv_{LV}, the impulsive delta V in local-vertical coordinates,

b) t_{IG}, the time of ignition for the thrusting maneuver.

5.3.10.2 Procedures

Figure 5.3.10-1 presents the P76 functional flow; Table 5.3.10-I is a summary of P76 DSKY procedures.

After the astronaut selects P76 (VERB 37 ENTR 76 ENTR), he is requested to validate the input t_{IG} (flashing VERB 06 NOUN 33). If the displayed value is the time that the CM executed the maneuver, the astronaut keys PRO; if it is not the correct time, he keys VERB 25 ENTR, loads the correct t_{IG}, and then keys PRO.

Next, the DSKY displays the three components of the impulsive $\Delta \underline{v}_{LV}$ (flashing VERB 06 NOUN 84) for the CM maneuver at t_{IG}. If any of the $\Delta \underline{v}_{LV}$ components are to be altered, the astronaut keys VERB 2x ENTR, loads the correct $\Delta \underline{v}_{LV}$, and then keys PRO. The PRO response causes the LGC-resident CM state vector to be updated to reflect the CM $\Delta \underline{v}_{LV}$; the RR mark counter is reset to zero; and the program exits via Routine R00. Viewing a flashing VERB 37, the astronaut keys in the appropriate response to call the next program, e.g., 20 ENTR to call P20.

5.3.10.3 Coordination Procedures

To ensure that the LGC-resident CM state vector is valid during P20 navigation, the astronaut should perform P76 as near the time the CM performs the maneuver as possible.

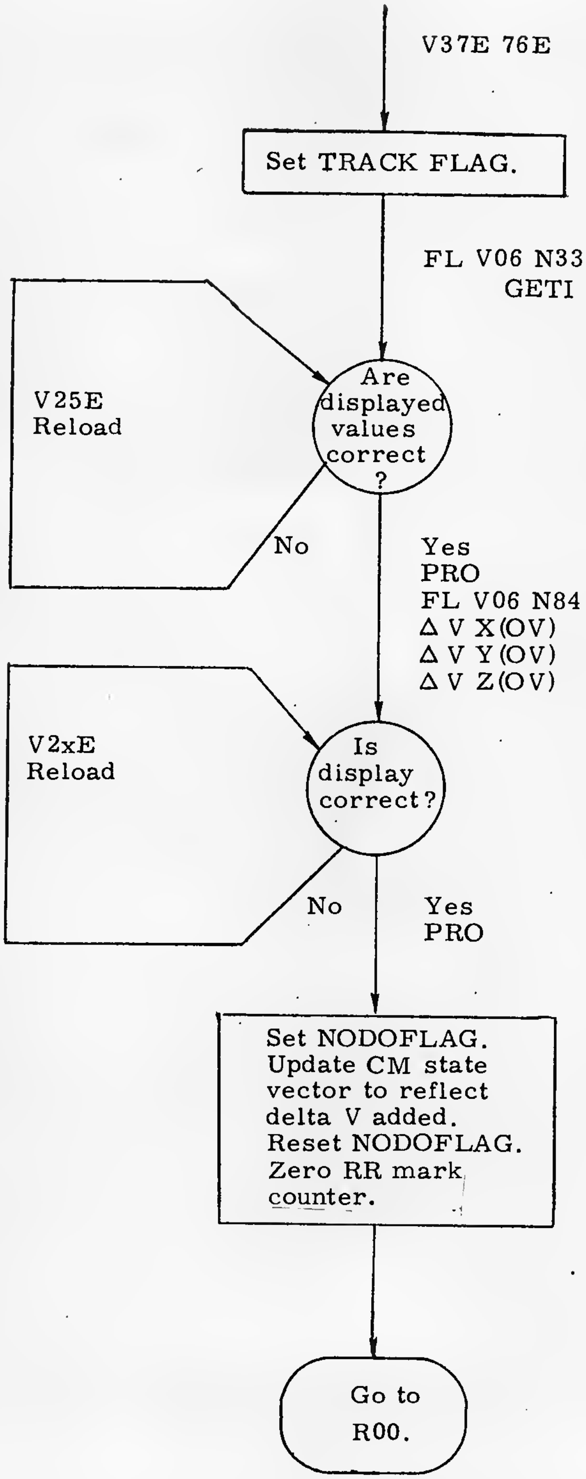

Figure 5.3.10-1. CM Target Δv Program (LM P76)

TABLE 5.3.10-I

SUMMARY OF CM TARGET Δv INPUTS (LM P76)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time of Ignition, t_{IG}	GET I	FL V06 N33	R1 ooxxx. hr R2 oooxx. min R3 oxx. xx sec	Automatically displayed by P76 for crew approval. A PRO response to displayed value indicates approval of value.
2.	Impulsive increment in velocity along the local vertical axes of the orbiting vehicle.	DELTA V(OV)	FL V06 N84	R1 xxxx. x X fps R2 xxxx. x Y fps R3 xxxx. x Z fps	Automatically displayed by P76 for crew approval. When a PRO is keyed, the value is used by the LGC.

At the completion of P76, and after a new program is entered, the astronaut can observe the CM's new orbital parameters by calling the Orbital-parameters Display Routine (R30).

5.3.10.4 Restarts

P76 is restart protected.

5.3.11 P77, Impulsive Δv—LGC

P77 notifies the LGC that the LM has changed its orbit by executing a thrusting maneuver that was not monitored by AVERAGEG. This notification is accomplished by updating the LGC-resident LM state vector to reflect the thrusting parameters for the LM maneuver.

5.3.11.1 Inputs and Outputs

After each LM maneuver of this type, the Lunar Module Pilot (LMP), using P77, updates the LM state vector by entering the following LM thrusting parameters via the DSKY:

a. $\Delta \underline{v}_{LV}$, the impulsive delta V in local-vertical coordinates,
b. t_{IG}, the time of ignition for the thrusting maneuver.

5.3.11.2 Procedures

Figure 5.3.11-1 presents the P77 functional flow; Table 5.3.11-I is a summary of P77 DSKY procedures.

After the astronaut selects P77 (VERB 37 ENTR 77 ENTR), he is requested to validate the input t_{IG} (flashing VERB 06 NOUN 33). If the displayed value is the time that the LM has executed the maneuver, the astronaut keys PRO; if it is not the correct time, the astronaut keys VERB 25 ENTR, loads the correct t_{IG}, and then keys PRO.

Next, the DSKY displays the three components of the impulsive $\Delta \underline{v}_{LV}$ (flashing VERB 06 NOUN 81) for the LM maneuver at t_{IG}. If any of the $\Delta \underline{v}_{LV}$ components are to be altered, the astronaut keys VERB 2x ENTR, loads the correct $\Delta \underline{v}_{LV}$, and then keys PRO. The PRO response causes the LGC-resident LM state vector to be updated to reflect the LM $\Delta \underline{v}_{LV}$; the RR mark counter is reset to zero; and the program exits via Routine R00. Viewing a flashing VERB 37, the astronaut keys in the appropriate response to call the next program, e.g., 20 ENTR to call P20.

5.3.11.3 Coordination Procedures

To ensure that the LGC-resident LM state vector is valid during P20 navigation, the astronaut should perform P77 as near the time the LM performs the maneuver as possible.

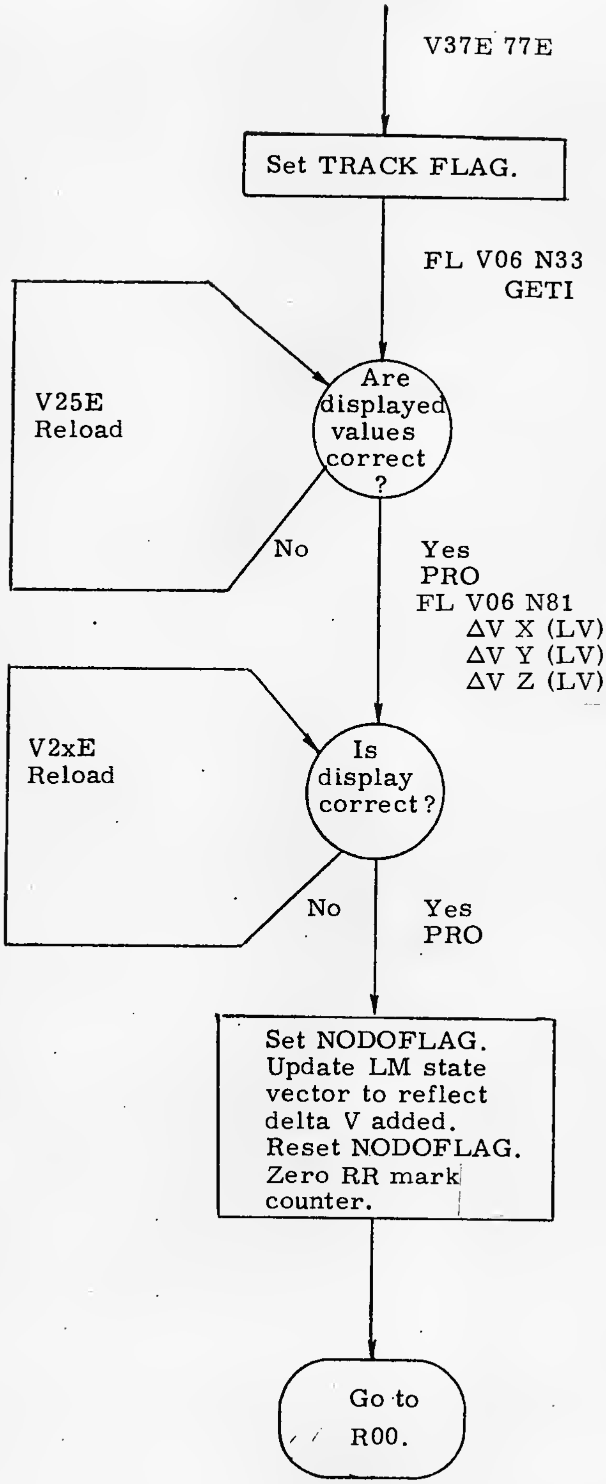

Fig. 5.3.11-1. Impulsive Δv Program (LM P77)

TABLE 5.3.11-1

SUMMARY OF IMPULSIVE Δv INPUTS (LM P77)

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time of Ignition, t_{IG}	GET I	FL V06 N33	R1 ooxxx. hr R2 oooxx. min R3 oxx.xx sec	Automatically displayed by P77 for crew approval. A PRO response to displayed value indicates approval of value.
2.	Impulsive increment in velocity along the local vertical axes of the orbiting vehicle.	DELTA V(LV)	FL V06 N81	R1 xxxx.x X fps R2 xxxx.x Y fps R3 xxxx.x Z fps	Automatically displayed by P77 for crew approval. When a PRO is keyed, the value is used by the LGC.

At the completion of P77, and after a new program is entered, the astronaut can observe the LM's new orbital parameters by calling the Orbital-parameters Display Routine (R30).

5.3.11.4 Restarts

P77 is restart protected.

SECTION 6.0

POWERED FLIGHT

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6.1 INTRODUCTION TO POWERED FLIGHT

Seven programs constitute the powered-flight major modes for the command and service module (CSM) and the lunar module (LM).* Two of the seven are monitor programs; three use input data from the targeting programs (refer to section 5.0) to control thrust direction and velocity-to-be-gained during automatic thrusting maneuvers; the remaining two use input data from the targeting programs to coordinate short, manually controlled maneuvers. All provide DSKY displays for the crew to monitor the maneuver's progress.

The command-module computer (CMC) powered-flight programs are as follows:

- P40, the Service Propulsion System (SPS) Maneuver Program—paragraph 6.2.1
- P41, the Reaction Control System (RCS) Maneuver Program—paragraph 6.2.2
- P47, the Thrust Monitor Program—paragraph 6.2.3.

The lunar-module guidance computer (LGC) powered-flight programs are as follows:

- P40, the Descent Propulsion System (DPS) Maneuver Program—paragraph 6.3.1
- P41, the Reaction Control System (RCS) Maneuver Program—paragraph 6.3.2
- P42, the Ascent Propulsion System (APS) Maneuver Program—paragraph 6.3.3
- P47, the Thrust Monitor Program—paragraph 6.3.4.

The calculations for steering the spacecraft are done in the cross-product steering loop. The name "cross-product" comes from the steering commands that are generated by taking the cross-product of two vectors. The term "steering loop" indicates that the steering computations are done repetitively in a predetermined cycle, using performance feedback and new guidance input to update output values. Refer to Figure 6.1-1, below.

Within the steering loop is a digital autopilot (DAP) loop for controlling the spacecraft attitude during powered flight; the DAP cycles between 10 and 25 times each second. Because DAP performance is different for the different vehicles, the DAP loop operation within the larger steering loop is discussed separately in the introductions to the CSM and LM vehicles, subsections 6.2 and 6.3, respectively.

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*In the LM, there are other powered flight programs for ascent and descent.

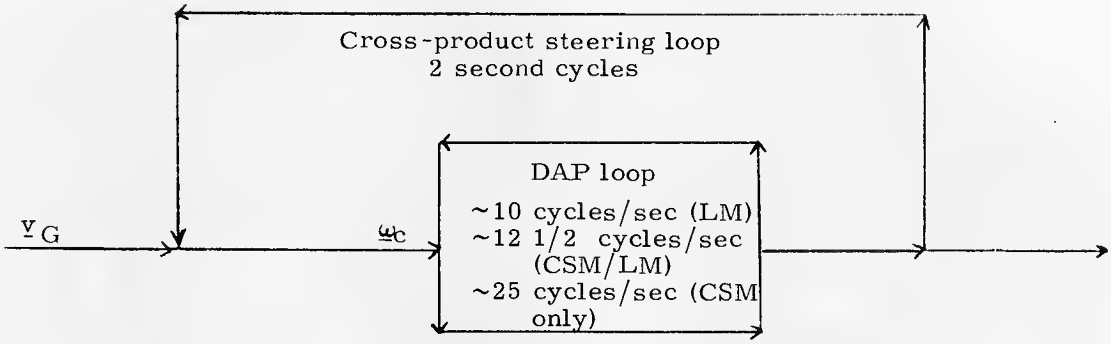


Figure 6.1-1. Steering and DAP Loops

All seven of the powered flight programs use the AVERAGEG Routine for state vector updating. AVERAGEG is discussed in paragraph 6.1.1. The CSM P40 and P41 and the LM P40, P41, and P42 use the cross-product steering subroutine to update the velocity-to-be-gained vector ($\underline{v}_G$); the CSM P40, LM P40, and LM P42 also use the subroutine to generate steering commands to the DAP, compute time from cutoff (t_{go}) and issue engine-off commands. Cross-product steering calculations are discussed in paragraph 6.1.2.

Despite dissimilarities in the powered flight programs, there is a basic pattern common to the logic of all. Figure 6.1-2 shows this basic logic pattern. Figure 6.1-3 presents a typical time line for a CSM P40 maneuver.

6.1.1 AVERAGEG Routine

The AVERAGEG Routine maintains an estimate of the vehicle state vector during noncoasting thrusting maneuvers. AVERAGEG computations are used whenever forces other than gravity are acting on the vehicle (for example, thrusting forces during boost, translunar injection, SPS, RCS, DPS, and APS burns; aerodynamic forces during boost and entry). In contrast with the Coasting Integration Routine, AVERAGEG is used when a short computing time is required.*

---

* The Coasting Integration Routine takes longer than AVERAGEG and uses multiple iterations to arrive at a precision solution.

Key V37E4 x E

↓

R02 — Checks IMU

↓

R60 — Maneuver to right attitude for thrust (CSM P40, P41 LM P40, P41, P42)

↓

R41 — Integrate state vector

↓

Start AVERAGEG
Start $\underline{v}_G$ updating — (CSM P40, P41 LM P40, P41, P42)

↓

Thrusting maneuver — Monitored by DSKY displays; steering commands to DAP (CSM P40, LM P40, LM P42)

↓

Engine-off

↓

Key V37E xx E
to terminate AVERAGEG

Figure 6.1-2. Powered-flight Logic

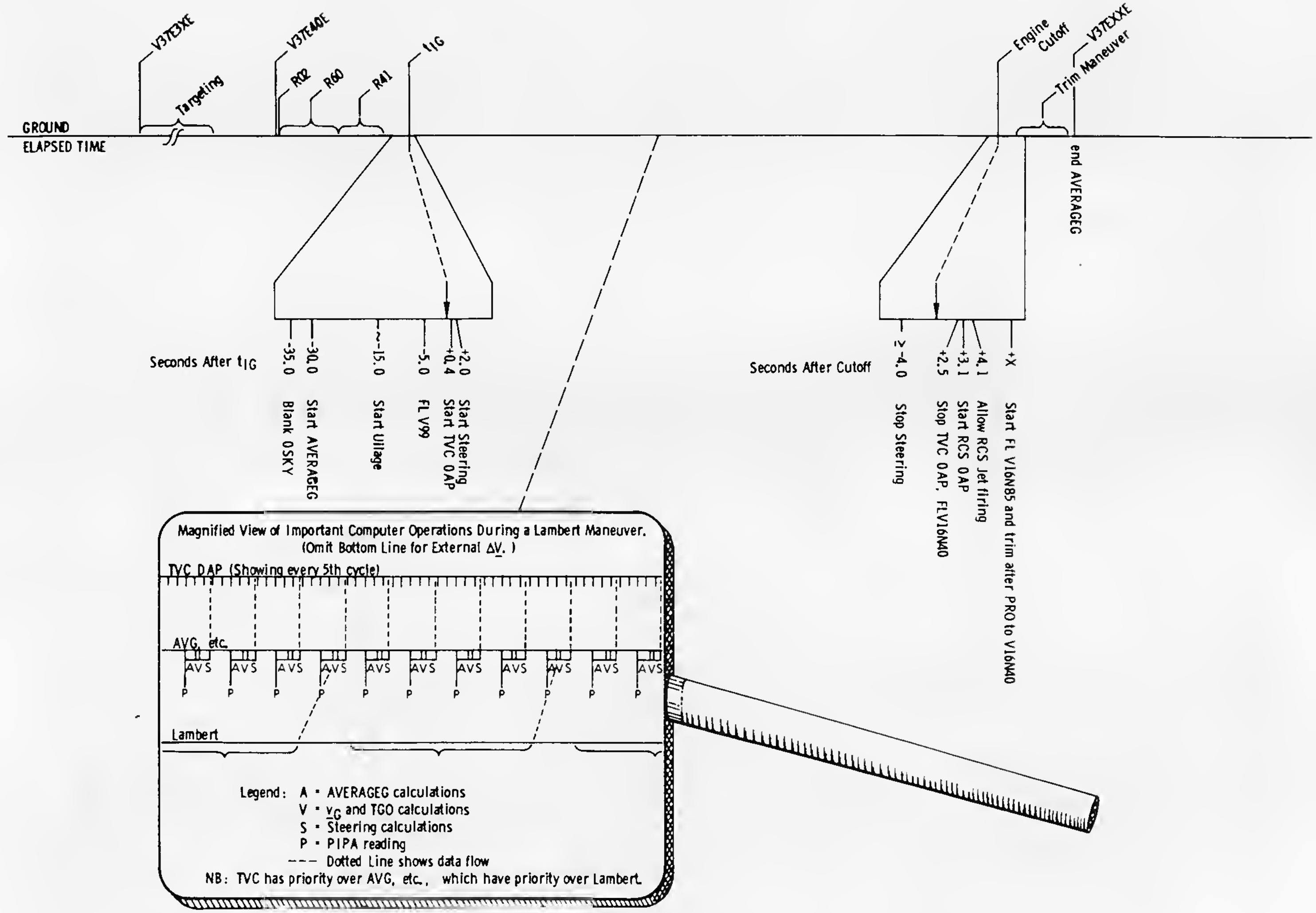


Figure 6.1-3. Typical Timeline for a CSM P40 Maneuver

In a 2-second computation cycle, the AVERAGEG Routine uses input position, velocity, and gravity acceleration vectors, as well as the velocity change measured by the PIPAs, to compute updated position and current gravity acceleration vectors. Updated velocity is then computed using (1) an average of current and past sample gravitational acceleration and (2) applied Δv. These outputs are used as inputs in the next AVERAGEG cycle.

The velocity change measured by the PIPAs is stored in the computer, from which it is read by the AVERAGEG routine. (See above.) But the PIPAs have an inherent bias error. During thrusting, the bias error is small in proportion to the movement measured by the PIPAs. When thrusting terminates, however, the PIPAs continue to measure movement, and the uncompensated bias error becomes large in proportion to the movement measured. Thus, to avoid disproportionate accumulations of bias errors, AVERAGEG should be terminated as soon as possible after thrusting terminates.

The earth-gravity-subroutine computation includes a single oblateness term; the lunar computation includes none. Section 5, GSOP, paragraph 5.3.2 gives details of the computation.

6.1.2 Cross-product Steering Subroutine

The cross-product steering subroutine extrapolates $\underline{v}_G$ for $\underline{v}_G$-updating, updates the CSM mass, generates steering commands to the DAP, computes time from cutoff, and issues engine-off commands. Cross-product steering nulls the input $\underline{v}_G$ by controlling the thrust direction: the combination of properly oriented thrust acceleration and inherent gravitational acceleration eventually nulls the guidance $\underline{v}_G$. Thrust is terminated when the desired velocity increment has been achieved. It is the function of guidance to ensure that nulling the $\underline{v}_G$ will achieve the desired velocity.

The general objective of cross-product steering is to align $(\underline{a}_T - c\underline{b})$ with $\underline{v}_G$, where:

$\underline{v}_G = \underline{v}_R - \underline{v}$ = required velocity - actual velocity

$$\underline{b} = \frac{d\underline{v}_R}{dt} - \underline{g}$$

$\underline{a}_T$ = thrust acceleration

c = a mixing factor empirically chosen to minimize fuel consumption and optimize or control vehicle attitude change during the maneuver. In

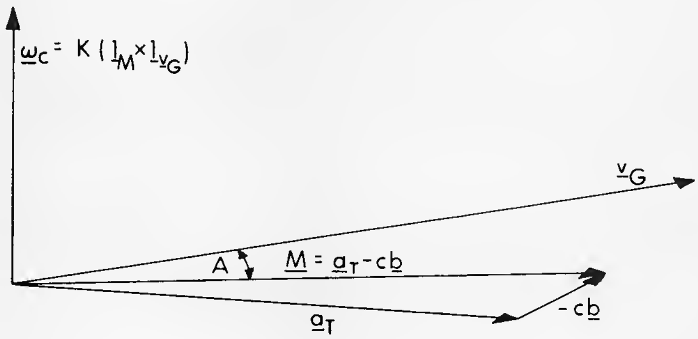
the LM, c = 0; in the CSM, the nominal values of c are as follows for the programs listed:

P30, P31, P32, P33, and P36 (External Δv)	0
P34, P35, (Lambert)	1
P37	1/2

Steering, then, generates the rate-command inputs to the CSM TVC DAPs. These inputs are derived from the components of a vector $\underline{\omega}_c$ expressed in body-axis coordinates. (The roll component is ignored;* the pitch and yaw components are sent to the pitch and yaw TVC DAPs, respectively.) The vector $\underline{\omega}_c$ is the cross-product between the unit vectors along $\underline{v}_G$ and $\underline{M} = \underline{a}_T - c\underline{b}$, multiplied by a constant of proportionality K, the steering gain. (See the figure below.) The equation is shown as follows:

$$\underline{\omega}_c = K\,(\underline{1}_M \times \underline{1}_{\underline{v}_G})$$

The magnitude of $\underline{\omega}_c$, representing the total rate commands, is proportional to the angle A, and is in the direction such that $\underline{M}$ will rotate towards $\underline{v}_G$; $\underline{\omega}_c$ vanishes when the desired alignment is achieved (i.e., A = 0). Controlling $\underline{M}$ is, essentially, controlling $\underline{a}_T$ because (1) $-c\underline{b}$ is small relative to $\underline{a}_T$ (for external Δv burns, $c\underline{b}$ is identically zero), and (2) $\underline{a}_T$ is relatively fixed in the body-axis frame since thrust passes through the c.g. in the steady state.



*Since body orientation about $\underline{a}_T$ is not critical, roll control can be handled independently via a separate roll autopilot.

K is chosen to balance the conflicting requirements of speed of response and closed-loop stability. The initial burn attitude is chosen to align $\underline{v}_G$ and $\underline{M}$ at ignition, $(\underline{a}_T - c\underline{b}) \times \underline{v}_G = 0$. For external Δv burns, where $c = 0$, initial alignment satisfies the equation $\underline{a}_T \times \underline{v}_G = 0$. The value of $\underline{a}_T$ used is a pre-burn estimate based on nominal thrust and expected c.g. offsets.

For the CSM P40 and P41 and the LM P40, P41, and P42, the cross-product steering subroutine is used to update the $\underline{v}_G$ vector and to compute DSKY displays for monitoring the maneuver's progress. For the CSM P40, LM P40, and LM P42, the computations are used to generate steering commands and to update the estimate of engine cut-off time. In the P41s, these two functions are performed by the crew with the assistance of the displayed updated $\underline{v}_G$.

The cross-product steering functions are executed every 2 seconds, i.e., every time an updated state vector is provided from AVERAGEG computations. No steering commands are computed until t_{IG} + 2 seconds or during the last 4 seconds of a maneuver. Steering is not implemented for burns of less than 6 seconds (impulsive burns), which are done in attitude hold.

There are two modes of cross-product steering computations—External Δv and Lambert Aimpoint. Figure 6.1.2-1 gives a general flow of the cross-product steering logic.

6.1.2.1 External-Δv Guidance Mode

The External-Δv mode is characterized by a nonrotating thrusting maneuver, i.e., it uses a single thrust direction. The maneuver is done at a fixed attitude except when there is an initial misalignment of thrust, $\underline{v}_G$, and c.g. (center of gravity); c.g. motion; or DAP commands to compensate for slosh, etc.

The External-Δv mode is used to control maneuvers in which a constant thrust attitude is desired. Such maneuvers may be targeted in either the CSM or the LM P30, P32, and P33 or in CSM P31 and P36. Examples of External-Δv maneuvers are as follows:

<u>Command and Service Module</u>

Phasing maneuvers	P30
Coelliptic Sequence Initiation (CSI) rescue	P32
Constant Delta Altitude rescue (CDH)	P33
Some out-of-plane maneuvers	P30
Trans-earth injection (TEI)	P30
Lunar orbit insertion (LOI)	P30
Midcourse correction	P30
Plane change (PC)	P36
Height adjustment (HAM)	P31

Concentric sequence initiation (CSI)	P32
Constant delta height (CDH)	P33
Some out-of-plane maneuvers	P30
CMC—P37 targeted maneuvers using DPS	P30
Abort TEI using DPS/APS	P30

The guidance program accepts input data from the above targeting programs in the form of an impulsive $\Delta \underline{v}$ required in local vertical coodinates at a specified time of ignition (t_{IG}). Since the change of velocity cannot be made instantaneously, the in-plane component of the initial $\underline{v}_G$ is rotated about the angular momentum vector at t_{IG} by half the predicted central angle of the burn. This rotation accounts for real-burn gravitational forces, which were not considered in the impulsive $\Delta \underline{v}$ targeting calculations. The effect is similar to the biasing of the ignition time by 1/2 the anticipated burn time in P37. After it has computed this compensated $\Delta \underline{v}$, the program overwrites the contents of NOUN 81 (local vertical $\Delta \underline{v}$ required) from the prethrust program. Thus, should the crew call a NOUN 81 display after entering the thrusting program, they will notice that the components of $\Delta \underline{v}$, as displayed in NOUN 81, have changed.

Figure 6.1.2-1 shows how the External-Δv mode fits into the Cross-product Steering Routine for the CSM.

6.1.2.2 Lambert-aimpoint-guidance Mode

The Lambert-aimpoint-guidance mode controls the spacecraft trajectory such as to intercept a given target position (aimpoint) at a given time. The thrusting maneuver has a built-in rate of change of thrust direction, since the Lambert computations periodically update the value of $\underline{v}_R$ during finite non-impulsive burns; no central angle rotation is required. (Refer to Figure 5.1-3.)

Such maneuvers may be targeted in the CSM by P34, P35, and P37. In the LM, Lambert-type maneuvers are done using ASTEER guidance. P34 and P35 target for such maneuvers. Examples of CSM Lambert maneuvers are as follows:

Rendezvous intercept	P34
Rendezvous midcourse maneuver	P35
Return-to-earth maneuvers	P37

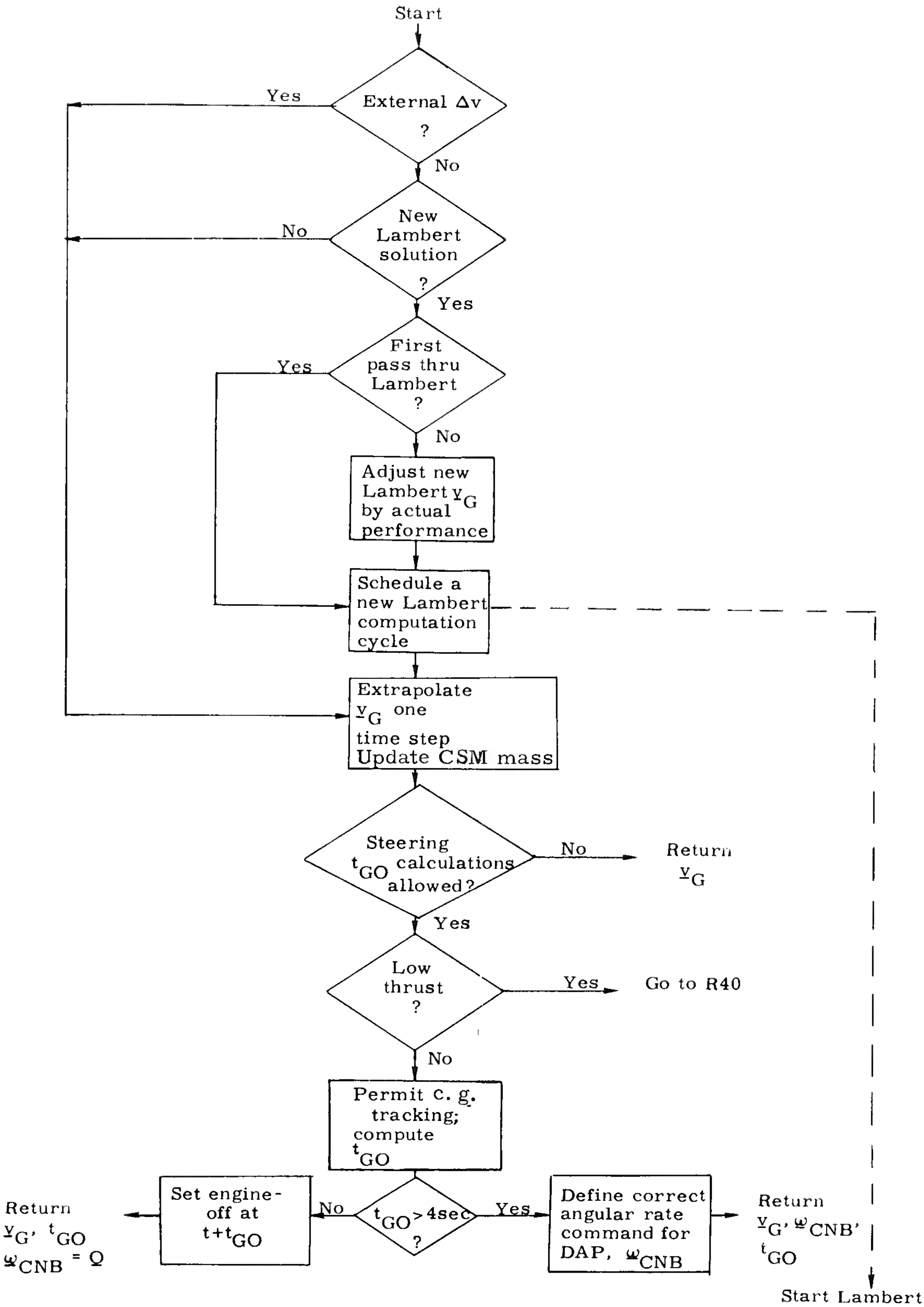


Figure 6.1.2-1. Logic Flow of CSM Cross-product Steering

The typical solution time for the Lambert calculations is 2 to 4 seconds (the COMP ACTY light will be illuminated during the calculations). Since there is often not a new Lambert solution at the beginning of the 2-second cross-product steering cycle, values from the last complete Lambert computation are used to determine $\underline{v}_G$ by extrapolating current values until new data are available from a complete Lambert computation.

In CSM P41, and in the manual trim maneuver of the CSM P40, there is a $\underline{v}_G$-bounce phenomenon that causes the displayed value of $\underline{v}_G$ to change unevenly at the end of a Lambert cycle. This bounce is due to 1-csec time quantization in time-of-flight.

Ordinarily, the Lambert Routine seeks a $\underline{v}_R$ in the plane of the initial and final position vectors ($\underline{r}$ and $\underline{r}_T$). (See Fig. 6.1.2-2 a.) The $\underline{r}_T$ vector (the target vector), however, may be slightly out of the $\underline{r}$-$\underline{v}$ plane. Consequently, the computed $\underline{v}_R$ would be slightly out of $\underline{r}$-$\underline{v}$ plane, resulting in $\underline{v}_G$ having a component perpendicular to the $\underline{r}$-$\underline{v}$ plane. (See Fig. 6.1.2-2 b.) The greater the magnitude of the out-of-plane component, the more energy would be necessary to acquire $\underline{v}_G$. The most serious problem occurs in the 180-deg transfer angle condition (i.e., the angle between $\underline{r}$ and $\underline{r}_T$ is near 180 deg), since the $\underline{r}$-$\underline{r}_T$ plane could be perpendicular to the $\underline{r}$-$\underline{v}_R$ plane and $\underline{v}_G$ could be totally out of plane.

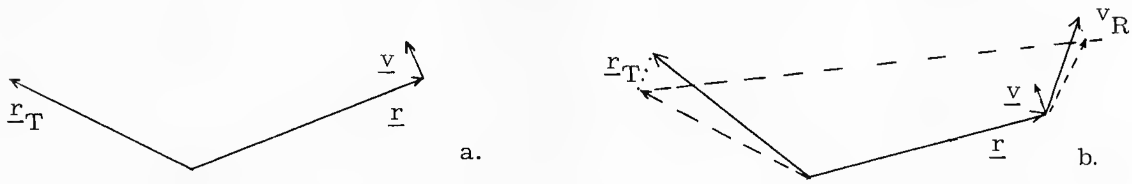


Figure 6. 1. 2-2. Lambert Routine Vectors

A switch is set in the Lambert targeting programs (P34 and P35) to indicate whether $\underline{r}_T$ is within a specified cone angle, ϵ, measured from the 180-deg transfer angle condition. If within this cone angle, $\underline{r}_T$ is rotated into the active vehicle orbital plane, so that excessive plane change and Δv are avoided. In the intercept targeting programs (P34 and P35) the cone angle ϵ is set at 15 deg, and active vehicle transfer angles between 165 deg and 195 deg are normally avoided in the targeting procedure. If a transfer angle condition falling within this 180 ±15-deg sector is either

intentionally selected, during the TPI targeting (P34), or is the result of a rendezvous midcourse correction maneuver (P35) during an intercept trajectory targeted for more than 180 deg, the Lambert Routine increases the cone angle ϵ to 45 deg so that the active vehicle transfer angle will not change from inside, to outside, the cone angle during the powered maneuver. Such a condition is undesirable since the intercept trajectory would be retargeted during the powered maneuver. Likewise, if the initial transfer angle falls outside the 15-deg cone angle of P34 and P35, ϵ is decreased to 10 deg to reduce the possibility of the transfer angle changing from outside to inside the cone angle during a powered maneuver.

Figure 6.1.2-1 shows how the Lambert mode fits into the Cross-product Steering Routine. When no new Lambert solution is available, $\underline{v}_G$ is extrapolated from the current $\underline{v}_G$. When a new Lambert solution is available, the computed value of $\underline{v}_G$ is corrected by adding the incremental difference between the calculated, expected change in v and the PIPA-measured $\Delta\underline{v}$. A new Lambert computation is scheduled to begin at the end of the cross-product steering calculations. The corrected Lambert $\underline{v}_G$ is then used as input to the extrapolation of $\underline{v}_G$.

ASTEER is an LGC modification of the Lambert steering concept. It can be used because of the characteristics of lunar orbit rendezvous maneuvers (i.e., for small powered flight maneuvers, variation in the semimajor axis (a) of the desired Lambert solution is negligible). ASTEER guidance is like Lambert guidance, except (1) $\underline{v}_G$-bounce is eliminated and (2) computation load is reduced (since the semimajor axis does not have to be recalculated).

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6.2 CMC POWERED-FLIGHT PROGRAMS

The Command Module Computer (CMC) has a thrust monitor program (P47) and two thrust control programs—P40 for Service Propulsion System (SPS) maneuvers and P41 for Reaction Control System (RCS) maneuvers. The cross-product steering cycle, which generates steering commands in P40, has been discussed in paragraph 6.1. The digital autopilot (DAP) implements these commands.

During powered flight, the thrust vector control (TVC) DAP controls the spacecraft attitude in accord with steering commands from the cross-product steering computations. Pitch and yaw control of the vehicle is achieved through the deflection of the single gimbaled SPS engine mounted on the service module, while attitude control about the roll axis is provided by the TVC ROLL DAP using the RCS jets.

The TVC DAP computes gimbal-servo commands in response to computed errors between commanded and measured attitudes. The operation takes place as follows:

a. The CMC steering loop computations generate incremental attitude commands in inertial coordinates and transform them into body coordinates.
b. A coupling data unit (CDU) measures the gimbal angles of the inertial measurement unit (IMU) and generates pulses representing small, fixed increments in these angles. These pulses are transmitted to the CMC where they are summed and held in a CDU register.
c. The CDU register is sampled regularly by the DAP program, which back-differences the CDU angles to obtain the incremental variations over each sampling interval.
d. The CDU increments over each sampling interval are then transformed into body coordinates and subtracted from the commanded increments generated by the steering program.
e. The resulting differences represent attitude-error increments, which are then summed to form attitude errors in body coordinates. Small initial attitude errors resulting from an ullage maneuver (RCS thrusting to settle the SPS propellant) prior to SPS thrusting are neglected in the CSM/LM DAP, which zeros the error registers at ignition. This is done to avoid exciting the bending modes by the effects of initial errors. In the CSM, where bending is less of a problem, the errors are correctly initialized.
f. The respective attitude errors are fed to the pitch and yaw compensation filters, whose outputs contribute to the commands to the engine-gimbal

servos for pitch and yaw.

g. The total command signal to each engine-gimbal servo is made up of the component from the compensation filter plus another component from a thrust misalignment correction (TMC) loop. The latter component serves to bias the total command so that a zero output from the compensation filter will cause the thrust vector to pass exactly through the center of gravity (c.g.) when there is no c.g. motion and no motion of the thrust vector relative to the commanded angle.

The TVC ROLL DAP is designed to provide attitude and rate control about the roll axis by the use of the RCS jets. Its function is strictly attitude hold. The orientation of the CSM about the roll axis is held within a 5-deg deadband throughout the burn. The outer-gimbal angle of the IMU, which is parallel to the vehicle roll axis, is read and processed to yield approximate roll-attitude and roll-rate measurements. A switching logic in the phase plane is then used to generate jet commands to the RCS jets. The switching logic divides the phase plane into three regions: jet firings for negative torque, jet firings for positive torque, and coast. The operating point in the phase plane is computed every 0.5 sec and jet firings are commanded only if the 5-deg deadband is exceeded. For successive torque commands of the same sign, jets are fired from alternate quad pairs. Normal procedure, however, is for the crew to disable one quad during a burn, which means that a jet failed on will produce a diverging roll attitude error.

Operation of the TVC DAP during an SPS burn is completely automatic, requiring no inputs from the crew. Before the burn, however, the crew may enter the CSM and LM weights or the estimated engine-trim angles in the pitch and yaw planes. (This entry is required after a vehicle configuration change, such as the LM undocking; at other times it is optional, to be made only if the crew is dissatisfied with the pad-loaded or computed values. The values are displayed in R03. Refer to paragraph 9.2.1.) Also, by keying in VERB 46 ENTR, the crew can change the CSM/LM compensation filter during a burn. This is a backup mode in case of a slosh instability; it will probably never be used.

The gains for the ROLL DAP and TVC DAP filters are established initially and updated using a small AGC program called TVCMASSPROP. This program, which is called every 10 sec by TVCEXEC, computes piecewise-linear approximations to the curves of I_{xx}, I_{AVG}, and I_{AVG}/Tl_x versus CSM propellent weight. These curves are given in parametric form, with LM mass as the parameter.

P40 initiates the operations of the TVC DAP after ignition. At 0.5-sec intervals, ROLL DAP and a routine to update the FDAI needles are called. Four sec before the end of the burn, the engine shutdown sequence is begun. After SPS engine shutdown, there is a 2.5-sec delay while the TVC DAP continues to function as the thrust level decays. RCS jet firings start approximately 1.5 sec later. At the end of the burn, there is an automatic update of the engine trim estimates from the thrust misalignment correction (TMC) loop, to be used for the next burn.

The performance of the TVC DAP is monitored via the FDAI attitude-error needles. Needle updates are made every 0.5 sec. During changeover from RCS to TVC, there is a short period (0.5 to 1 sec) during which the needles will be zeroed. After this period, in the CSM configuration, the pitch and yaw errors are reestablished with the values left by the RCS DAP. For the CSM/LM, the needles are not reestablished with the RCS errors.

In addition to the FDAI attitude-error needles, the crew can also monitor the Stabilization and Control System (SCS) rate needles and the engine gimbal-position-indicator (GPI) needles. Following the completion of the burn, the residual cross-axis velocity components are displayed on the DSKY in NOUN 85. Although when the ROLL DAP calls for jet-firings, the logic assumes the firing of alternate pairs of jets to minimize the effect of jet failures; operationally, only one jet pair is enabled by the crew. This ensures that the crew will notice if a jet fails on (the roll error will diverge), and the failed jet can then be disabled.

The RCS digital autopilot (RCS DAP) can be selected by the crew to provide rotational and translational control of the vehicle before and after a P40-guided SPS maneuver. It can also be selected to provide the same control before, during, and after a P41-guided RCS maneuver. During these times, a desired vehicle state (i.e., a desired attitude and rotation rate) can be specified. By means of a phase-plane switching logic and a jet-firing logic, the RCS DAP will maintain the difference between actual and desired vehicle state to within a certain tolerance (deadbands on attitude and rate). If the difference is within the tolerance, the RCS DAP will request no action. If, however, the difference exceeds the tolerance, the RCS DAP will cause RCS jets to be fired to bring the difference back within tolerance.

P40 will compute a pre-burn state and, with crew approval, the RCS DAP will use this as its desired state. Two ways of changing the desired state are use of the rotational hand controller and execution of the attitude maneuver routine R60.

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6.2.1 P40, Service Propulsion System (SPS) Maneuver — CMC

The powered flight guidance program, P40, handles the timing of SPS maneuvers. During burns, P40 maintains the CSM state vector, guides the thrust direction so as to achieve the desired velocity at the end of the maneuver, and provides the crew with a monitor of the maneuver's progress. P40—which may be used when a change-of-orbit maneuver is required—and the SPS are used for big burns with a manually controlled RCS trim maneuver at the end.

For a GNCS-controlled maneuver, P40 is used for a large velocity-to-be-gained; i.e., when $|\underline{v}_G|$ is greater than, or equal to,

$$\frac{F_{SPS}}{m} \cdot \Delta t_{MIN}$$

In the expression above, F_{SPS} is the thrust of the SPS engine (about 20,500 lb), m is the mass of the total vehicle (including the LM if it is attached), and Δt_{MIN} is the minimum burn time for which the particular SPS engine being considered has been successfully tested. Currently, Δt_{MIN} equals 0.5 sec.

A prethrust program, P3x, establishes the parameters needed for thrust control guidance. After the appropriate P3x has been performed, the astronaut must not select another P3x, P7x, or P23 before the burn. These programs use some of the same variable computer storage locations and would destroy the thrusting parameters established by the original P3x for this burn. Since mark incorporation would change the current state vector without correspondingly changing the thrusting parameters, VHF or Optics marks should not be accepted in P20 (Option 0 or 4) between P3x and P40. If P20 had been previously selected, however, it may continue to run in the background. (The mark incorporation function, is turned off by P3x.)

P40 uses the AVERAGEG routine for state vector updating, and cross-product steering for inputs to the TVC DAP, which controls the spacecraft attitude by positioning the engine bell during the burn.

6.2.1.1 State Vector Updating (AVERAGEG)

To keep the state vector up to date, the AVERAGEG routine takes into account two kinds of acceleration effects:

a. Gravity—by averaging the gravitational acceleration vector over 2-sec increments of time

b. Thrusting—by discrete velocity increments as measured by the PIPAs.

The state vector is updated by AVERAGEG every 2 seconds. AVERAGEG is used during burns because of its speed in updating. It should be terminated as soon as possible after the burn, however, to avoid accumulation of PIPA bias errors. Refer to subsection 6.1 for a more detailed discussion of AVERAGEG.

6.2.1.2 Cross-Product Steering (External Δv and Lambert Aimpoint)

Cross-product steering is used to guide the thrust direction. The two modes, External Δv and Lambert aimpoint, use the cross-product steering concept to control the thrust direction relative to the velocity-to-be-gained ($\underline{v}_G$) vector direction and to terminate thrust when the desired velocity increment has been achieved. (Refer to paragraph 6.1.2.) The two modes differ in method of computing $\underline{v}_G$. External Δv is characterized by a non-rotating burn and therefore uses a single initial value of $\underline{v}_G$ in its computations. Lambert aimpoint periodically recomputes $\underline{v}_R$ (required velocity) to achieve an intercept with the specified target vector at the specified time.

In External Δv, since the change of velocity cannot be made instantaneously, the routine uses a compensated inplane velocity to compute $\underline{v}_G$ rather than the actual desired-velocity-change vector.

The 2-second cycles of the cross-product steering functions often do not allow enough time to complete a Lambert computation in each cycle. Consequently, values from the last complete Lambert computation are used to determine $\underline{v}_G$ by extrapolating current values until new data are available from a complete Lambert computation. For a detailed explanation of the cross-product steering subroutine, External Δv, and Lambert aimpoint, refer to paragraphs 6.1.2, 6.1.2.1, and 6.1.2.2, respectively.

6.2.1.3 P40 Procedures

Tables 6.2.1-I and -II show P40 displays and extended verbs, respectively. Figure 6.2.1-1 is the program flowchart. Before entering P40, the Autopilot Data Load Routine (R03) and a prethrust program (P3x) must be performed. In addition, the IMU must be powered up and aligned.

The crew selects P40 (via the DSKY) at a time, specified by crew procedures, to allow sufficient time before ignition for prethrust activities, such as arming the

TABLE 6.2.1-I

DISPLAYS ASSOCIATED WITH P40 (CSM) (SHEET 1 OF 2)

DSKY	Initiated By	Purpose	Condition	Register
V05 N09E	Astronaut	Verify PROG alarm	00205 bad PIPA reading detected 00210 ISS not on 00220 IMU orientation unknown 01301 arc-sine or arc-cosine argument too large 01407 velocity-to-be-gained increasing 01703 time of ignition slipped	R1 xxxxx* R2 xxxxx R3 xxxxx
FL V50 N18	R60	Display required gimbal angles	OGA-roll IGA - pitch MGA - yaw	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
V06 N18	R60	Display of final gimbal angles	OGA IGA MGA	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
FL V50 N25	P40	Please perform SPS gimbal test drive option	00204 gimbal drive test option	R1 00204
V06 N40	P40	Display	Time from cutoff (TFC) Velocity to-be-gained Sum of acquired velocity	R1 xxBxx min, sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V99 N40	P40	Request SPS engine-on enable	---	---
FL V97 N40	R40	Low thrust detected	---	---
FL V16 N40	P40	Burn complete	Time from cutoff Remaining $\underline{v}_G$ magnitude Sum of velocity acquired	R1 xxBxx min, sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V16 N85	P40	Display remaining $\underline{v}_G$	Components of $\underline{v}_G$	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec

*The alarm codes are displayed as follows:
R1 contains the first alarm following error reset.
R2 contains the second alarm following error reset.
R3 contains the most recent alarm.

TABLE 6.2.1-I

DISPLAYS ASSOCIATED WITH P40 (CSM) (SHEET 2 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
FL V16 N44	R30	Display orbital parameters (R30)	Apogee altitude Perigee altitude Time of free fall	R1 xxxx.x n. mi. R2 xxxx.x n. mi. R3 xxBxx min, sec
FL V16 N54	R31	Display	Range Range rate Theta	R1 xxx.xx n. mi. R2 xxxx.x ft/sec R3 xxx.xx deg

TABLE 6.2.1-II

EXTENDED VERBS FOR USE WITH P40 (CSM)

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters	DSKY displays apogee, perigee, and time of free fall
83 ENTR	Do R31	Display rendezvous parameters	DSKY displays range, range rate and theta, the angle between local horizontal and the spacecraft X-axis

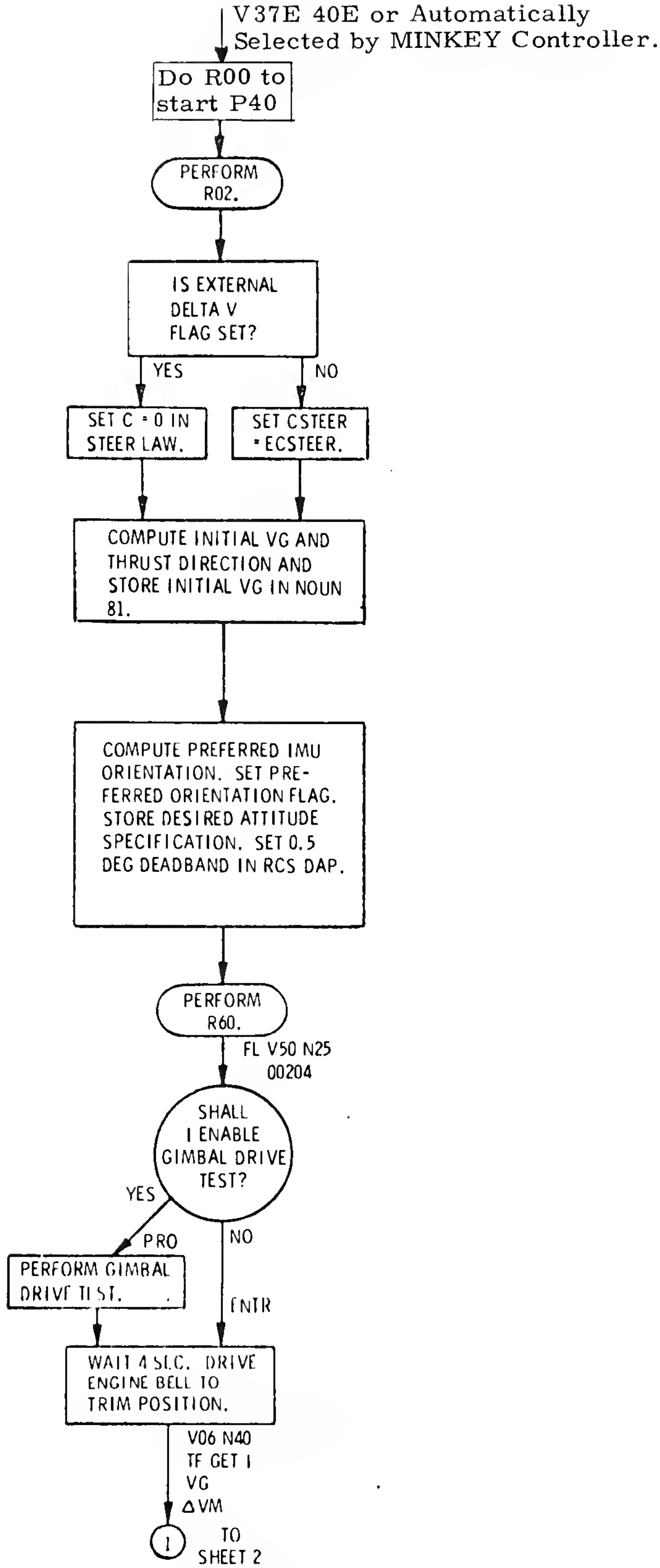


Figure 6. 2. 1-1. SPS Maneuver Program (CSM P40) (Sheet 1 of 3)

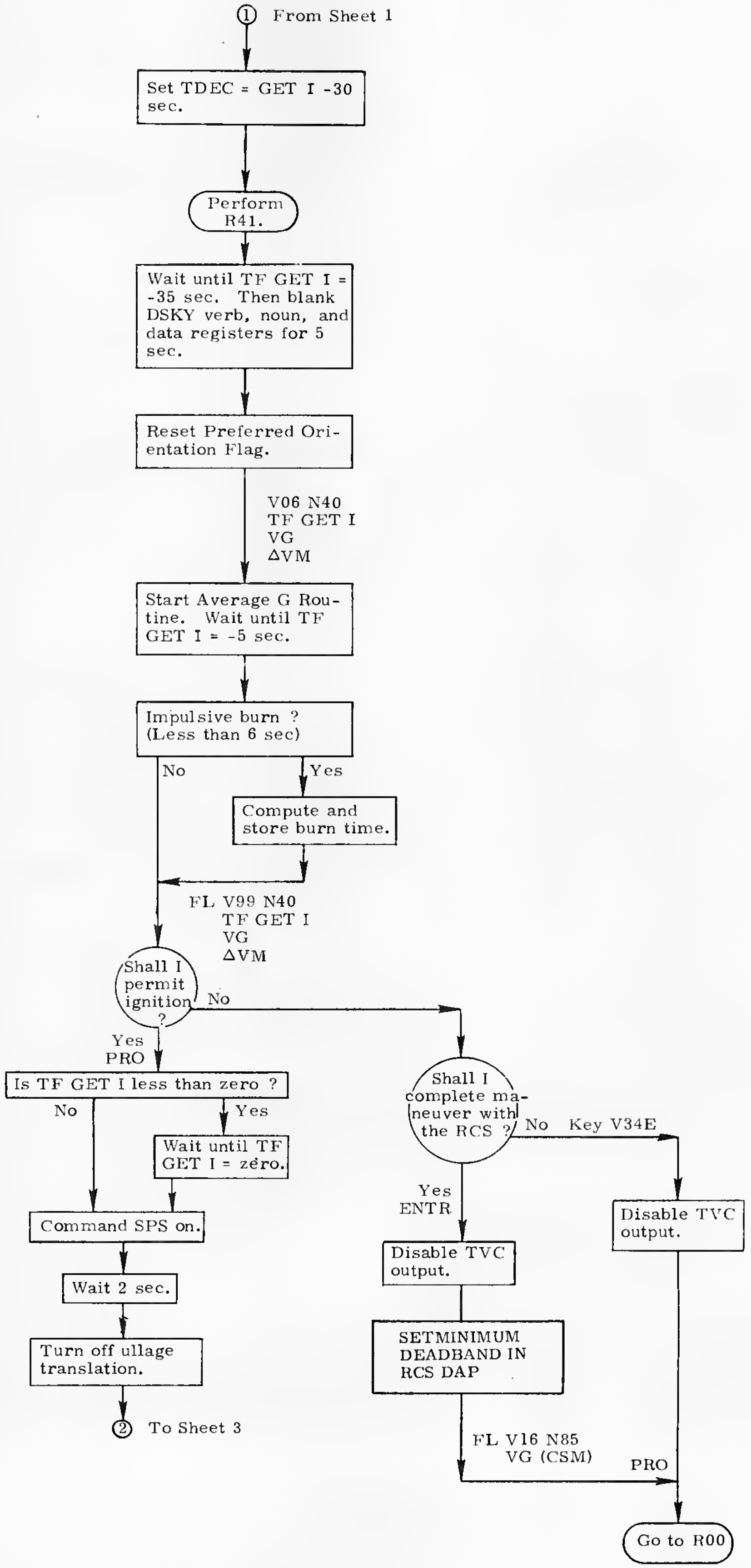
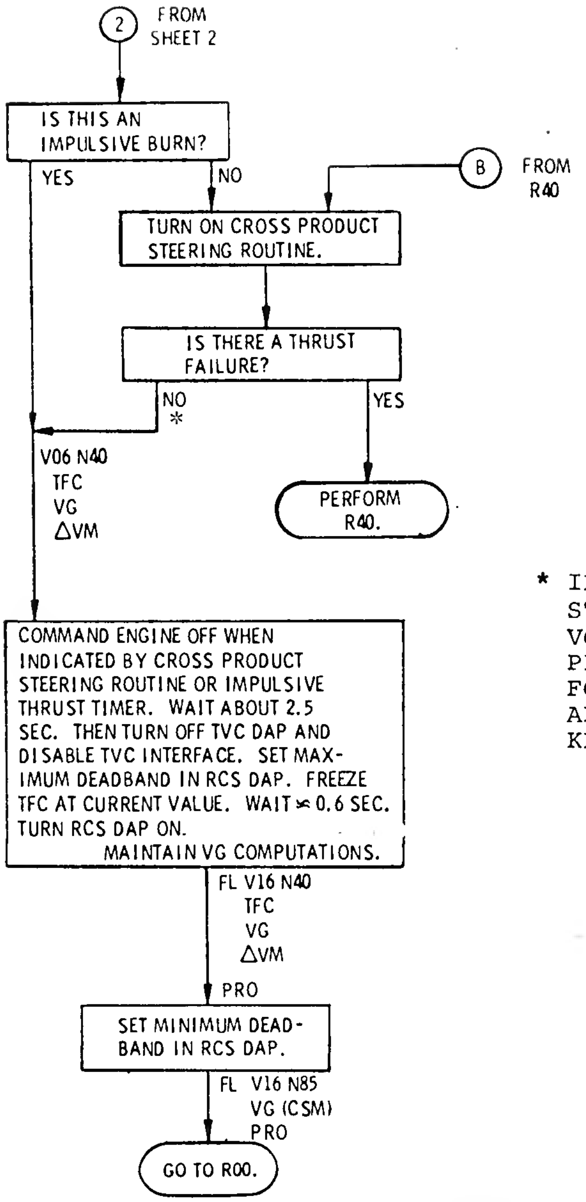


Figure 6.2.1-1. SPS Maneuver Program (CSM P40) (Sheet 2 of 3)



* IF CROSS PRODUCT STEERING DETECTS VG INCREASING PROG LT--ON. FOR DISPLAY OF ALARM CODE 1407 KEY V5N9E.

Figure 6.2.1-1. SPS Maneuver Program (CSM P40) (Sheet 3 of 3)

SPS and TVC, and performing R60. P40 can also be selected automatically by the MINKEY controller. Refer to paragraph 4.2.1. The program performs the IMU Status Check Routine (R02) and illuminates the PROG light if the ISS is off (alarm code equals 00210) or the IMU orientation is unknown (alarm code equals 00220).

At the completion of R02, the program computes the initial $\underline{v}_G$ and thrust direction and the preferred orientation matrix and then enters the Attitude Maneuver Routine (R60) and flashes VERB 50 NOUN 18. The desired gimbal angles are displayed to 0.01 deg in the following registers:

R1 = OGA, roll
R2 = IGA, pitch
R3 = MGA, yaw.

If the PROG light goes on at this point and the alarm code is 01301, the desired gimbal angles are indeterminate because the initial $\underline{v}_G$ is collinear with the stable member Y-axis. A maneuver to the desired attitude would produce gimbal lock.

If the crew chooses to have the attitude maneuver performed by the autopilot, the SC CONT switch must be placed in CMC, the CMC mode switch in AUTO, and then PRO keyed in response to VERB 50 NOUN 18, signaling the RCS DAP to begin the maneuver via R60.

During the maneuver, a non-flashing VERB 06 NOUN 18 displays the final gimbal angles, and the crew monitors the maneuver on the FDAI ball and needles. If gimbal lock is approached, or if it is desired to perform the entire maneuver manually, the crew uses the RHC to complete the maneuver. (Once the RHC is removed from detent, the automatic maneuvering routine ceases and can be re-initiated by responding with a PRO to the flashing VERB 50 NOUN 18.) A VERB 50 NOUN 18 display comes up upon completion of the R60 maneuver. The crew can then switch to SCS control and verify manual TVC. To exit from R60, the crew keys ENTR on VERB 50 NOUN 18.

Upon completion (or termination) of R60, the DSKY displays a flashing VERB 50 NOUN 25 with R1 containing 00204 (i.e., please perform SPS gimbal drive test option). The crew now arms the SPS and TVC. If the time to ignition is too short to allow the test to be performed, the crew can key ENTR. Normally, the crew keys PRO and monitors the test on the gimbal position indicator (GPI). In 2-second intervals, the SPS pitch gimbal is driven from 0 deg to +2 deg, from +2 deg to -2 deg, and from -2 deg to 0 deg. The SPS yaw gimbal then undergoes the same process.

After a 4-second delay, the program drives the engine bell to the trim position. Then the DSKY displays (and repeats every second) VERB 06 NOUN 40; the registers contain the following:

R1 = time from t_{IG}
R2 = magnitude of velocity-to-be-gained
R3 = sum of velocity increments acquired so far.

R1 is negative until t_{IG}. R2 initially contains the total velocity-to-be-gained and decreases as the maneuver proceeds. R3 should remain close to zero until ullage begins.

The program at this time enters the State Vector Integration Routine (R41), which integrates the CSM state vector ahead to t_{IG}-30 seconds. If R41 is not completed before t_{IG} -42.5 seconds, a program alarm (code 01703) is generated and the time of ignition is slipped until the integration is completed.

At t_{IG} -35 seconds, the DSKY is blanked for 5 seconds, then the VERB 06 NOUN 40 display returns. This is the beginning of the AVERAGEG and $\underline{v}_G$ updating cycles. From t_{IG} -30 until t_{IG} -25 seconds, the crew should watch R3 of the DSKY to be sure it does not exceed 2.0 ft/sec—a condition that indicates excessive PIPA bias and possible termination of the burn.

The crew should begin ullage shortly before t_{IG}—at a time determined from tables, depending on SPS fuel loading and the vehicle configurations. At this time, R3 will start to increase.

At t_{IG}-5 seconds, the DSKY display changes to flashing VERB 99 NOUN 40, requesting the SPS engine ignition go-ahead signal. The program provides the crew with the following three choices:

a. Avoiding the burn altogether by keying VERB 34 ENTR or by selecting a new program (VERB 37 ENTR xx ENTR)
b. Completing the maneuver under RCS power by keying ENTR
c. Going ahead with the SPS burn by keying PRO.

The program commands SPS ignition at t_{IG} and displays a non-flashing VERB 06 NOUN 40. The SPS THRUST light goes on, and the crew will feel an acceleration of approximately 0.2 to 1.0 g. If the crew fails to key PRO before t_{IG}, it may still PRO and the engine will light instantly.

During the burn, the astronaut should avoid using extended verbs since a VERB 97 display (low thrust) could be masked (i.e., not displayed on DSKY). In the Lambert mode, the computer may not have enough VAC area to perform both the Lambert computations and the extended verb. R1 displays time from engine cutoff. If R2 is increasing or if the PROG light goes on and alarm code 01407 occurs, there was probably an error in the initial attitude maneuver.

The crew can monitor the pitch and yaw attitude errors, as determined by the TVC autopilot, on the FDAI needles.

During the burn, if the system should detect a bad PIPA reading, the program will store an alarm code of 00205. The astronaut should switch to SCS control. If low thrust is detected by the computer, the program enters the Thrust Fail Routine (R40). The DSKY displays flashing VERB 97 NOUN 40 requesting action on thrust failure. (R40 is discussed in detail in paragraph 6.2.1.5.1.)

At cutoff time (t_{CO}), the program shuts off the SPS engine and the SPS THRUST light goes out. The DSKY displays a flashing VERB 16 NOUN 40 to indicate completion of the SPS burn; the crew replies by keying PRO. After 2 seconds, the DSKY displays a flashing VERB 16 NOUN 85 (the three components of the remaining $\underline{v}_G$, in control coordinates). The crew should use the RHC and THC to null the remaining $\underline{v}_G$ to a value specified in the checklist. The crew keys PRO to get to the flashing VERB 37.

The crew may desire to review the post-burn orbital parameters (R30), or it may desire to review the range and range rate to the LM (R31/R34).

AVERAGEG will continue running until a new major mode is selected; therefore this selection must be made immediately to avoid accumulation of PIPA bias errors.

6.2.1.4 Timelines

Figure 6.2.1-2 relates the P40 flowchart to crew observance and response.

6.2.1.5 Routines Associated with P40

6.2.1.5.1 <u>SPS Thrust Fail Routine</u>.—The SPS Thrust Fail Routine (R40) is automatically selected by P40 when low thrust is detected. Figure 6.2.1-3 gives a brief logical flow of R40. A flashing VERB 97 NOUN 40 notifies the crew of the thrust fail. If the engine comes back on at full strength, the crew can key PRO to

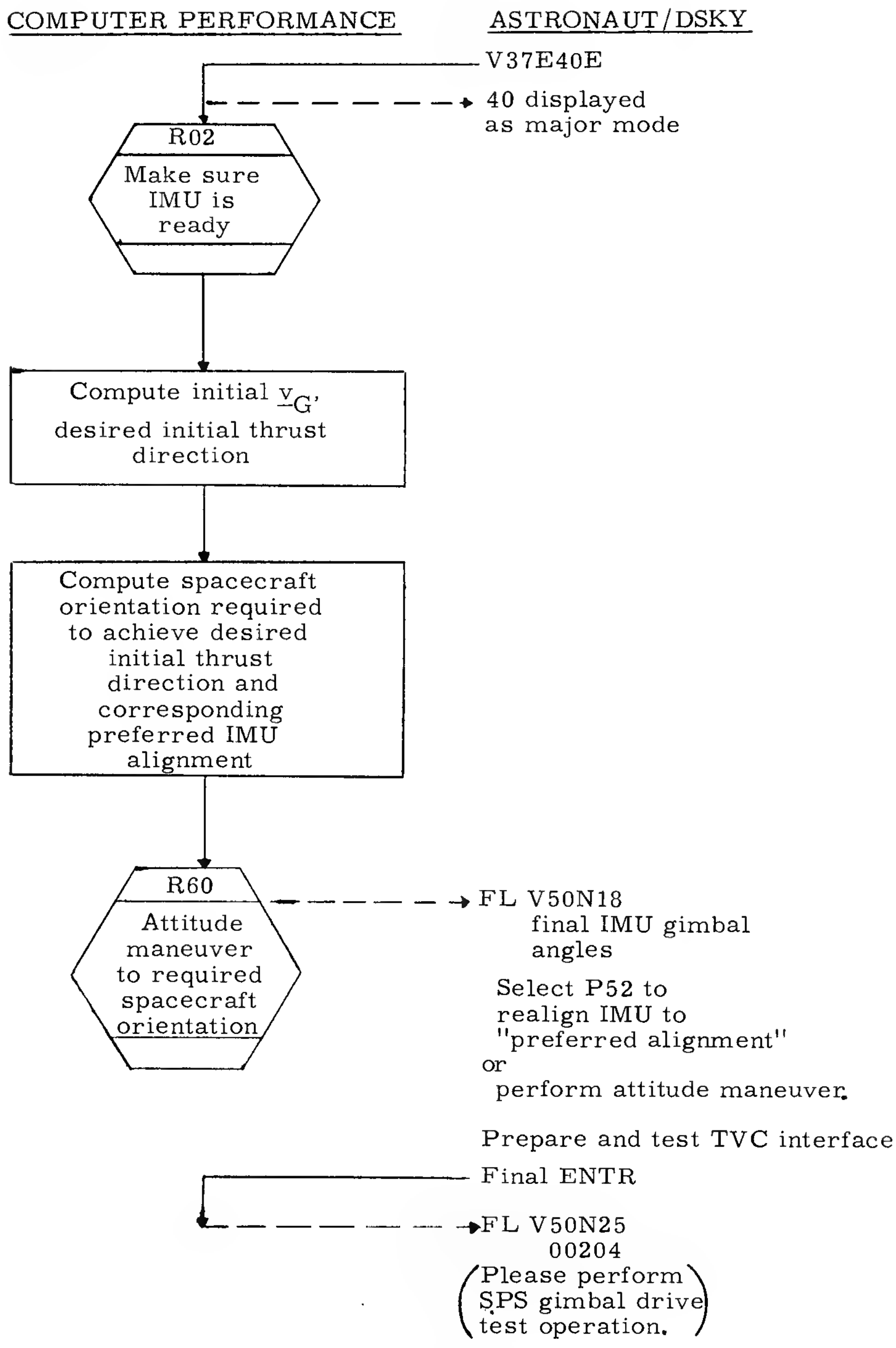


Figure 6.2.1-2. Timelines of SPS Maneuver Program (CSM P40) (Sheet 1 of 4)

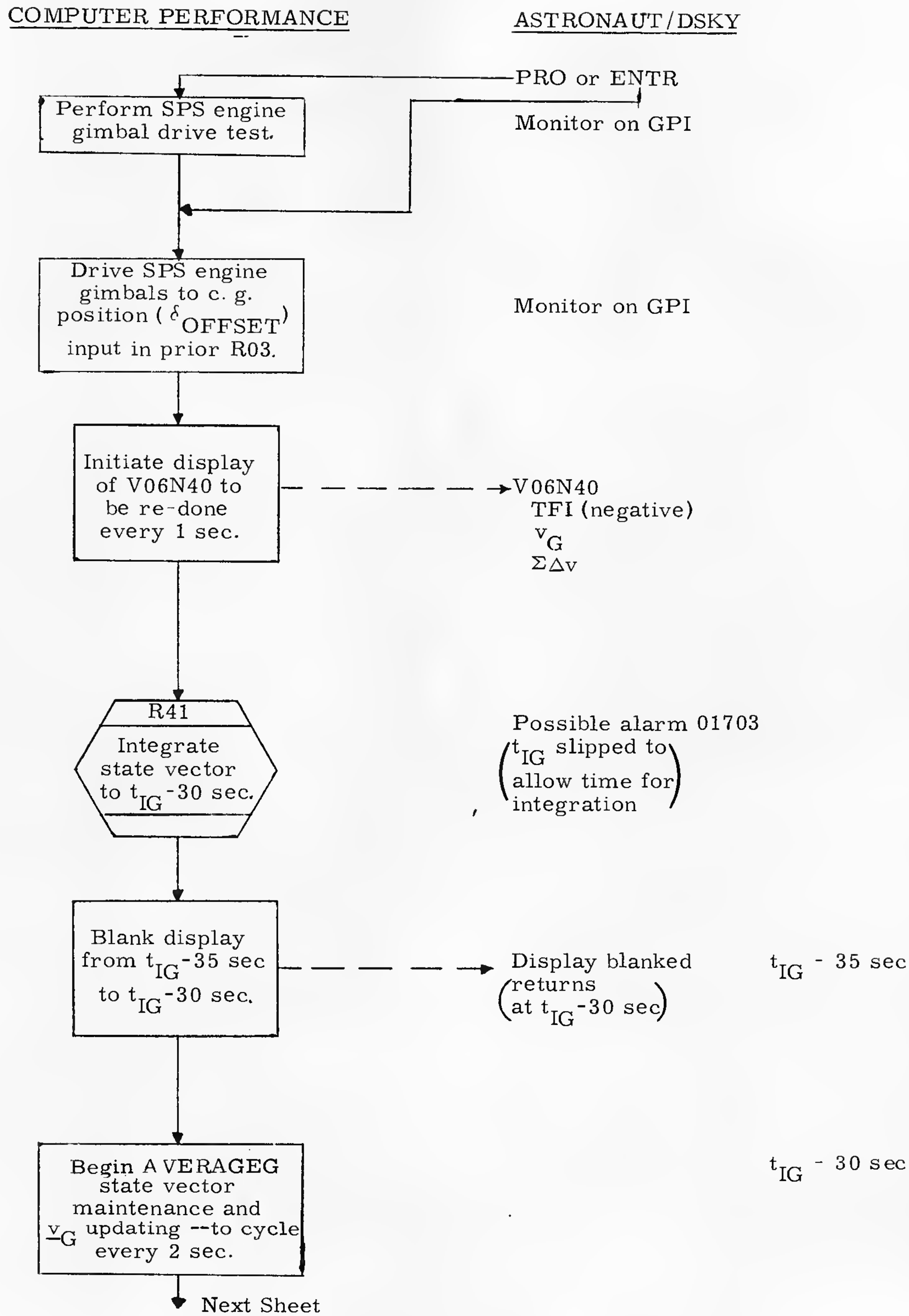


Figure 6. 2. 1-2. Timelines of SPS Maneuver Program (CSM P40) (Sheet 2 of 4)

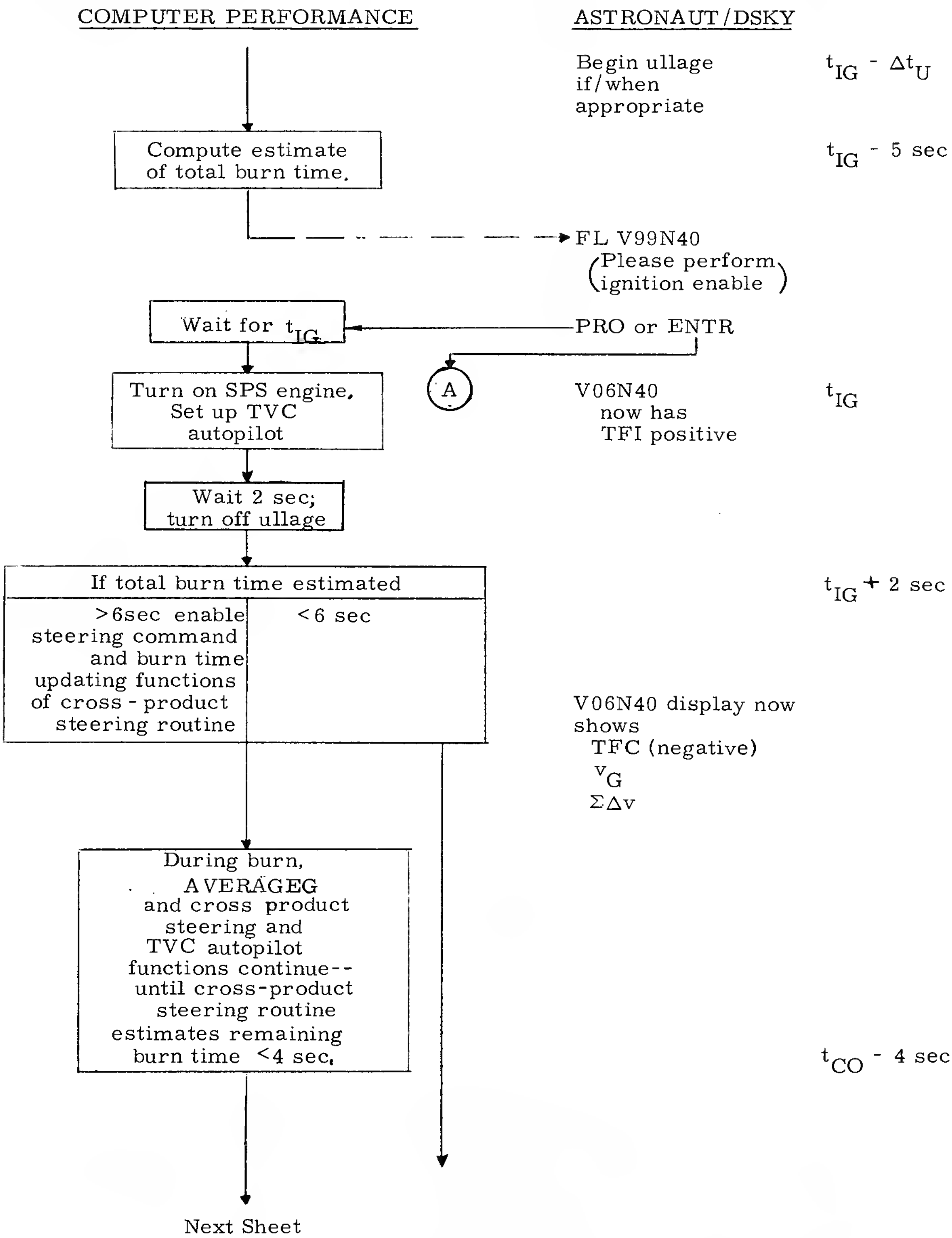


Figure 6.2.1-2. Timelines of SPS Maneuver Program (CSM P40)
(Sheet 3 of 4)

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Cross-product steering burn time estimate and steering command functions terminated.

Turn off SPS engine; return to RCS autopilot, in 2.5 sec +0.6 sec. Discontinue 1-sec updating of V06N40 display.

t_{CO}

FL V16N40
TFC at last cycle
v_G
$\Sigma\Delta v$
Disable TVC interface

A

PRO

FL V16N85
$\underline{v}_G$ in control coords
null out remaining $\underline{v}_G$ using hand controls

PRO

State vector maintenance continues until new major mode is selected.

R00
Terminate major mode.

FL V37
(Please select new major mode.)

Figure 6.2.1-2. Timelines of SPS Maneuver Program (CSM P40) (Sheet 4 of 4)

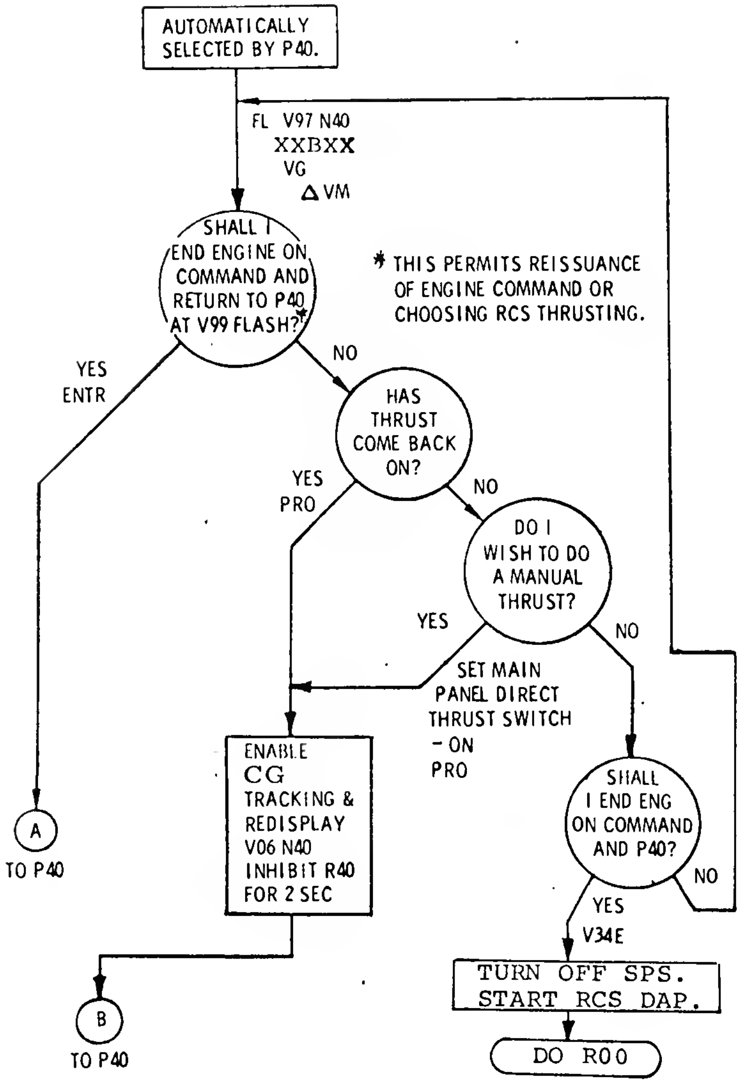

Figure 6.2.1-3. SPS Thrust Fail Routine (CSM R40)

continue the burn. To perform a manual thrust, the crew turns the DIRECT THRUST switch to ON and keys PRO.

To terminate the burn and attempt re-ignition or to attempt the maneuver by RCS power, the crew should key ENTR. Control will be returned to P40, where the time from t_{IG} display (R1) will be set to 59 min 59 sec, and the VERB 99 flash (occurring in about 2.5 seconds from return of control to P40) will behave as in a late ignition. The crew should key PRO for immediate ignition. The crew may choose to switch control of the burn immediately to the SCS. To terminate the burn altogether, the crew keys VERB 34 ENTR and turns the ΔV THRUST-A and -B switches to OFF when a new major mode has been requested.

6.2.1.5.2 State Vector Integration Routine.—Figure 6.2.1-4 is a flowchart of the State Vector Integration Routine (R41). R41 is automatically selected by P15, P40, P41, P47, P61, and P62. The purpose of this routine is to integrate the state vector ahead to the time that the AVERAGEG routine will be turned on by the thrusting program. If the state vector integration cannot be completed before the specified time, a program alarm occurs (alarm code equals 01703) and the t_{IG} is slipped.

6.2.1.6 Alarms

A list of alarm codes which may occur in P40 follows; detailed description of procedures to follow upon occurrence of these alarms is given below.

a. Alarm code 00205 occurs if a bad PIPA reading is detected.
b. Alarm code 00210 occurs if the ISS is not on.
c. Alarm code 00220 occurs if the IMU orientation is not known.
d. Alarm code 01301 occurs if the arc-sine or arc-cosine argument is too large.
e. Alarm code 01407 occurs if the velocity-to-be-gained is increasing.
f. Alarm code 01703 occurs if the t_{IG} is slipped.

Alarm code 00205 may occur during the thrusting maneuver. The crew should switch to SCS control.

Alarm codes 00210 and 00220 may occur immediately after the program is entered and the IMU Status Check Routine is called. They appear as PROG alarms on the DSKY when the crew keys VERB 05 NOUN 09 ENTR to identify the abnormality. When the alarm is identified, the crew depresses KEY REL and RSET and responds to flashing VERB 37.

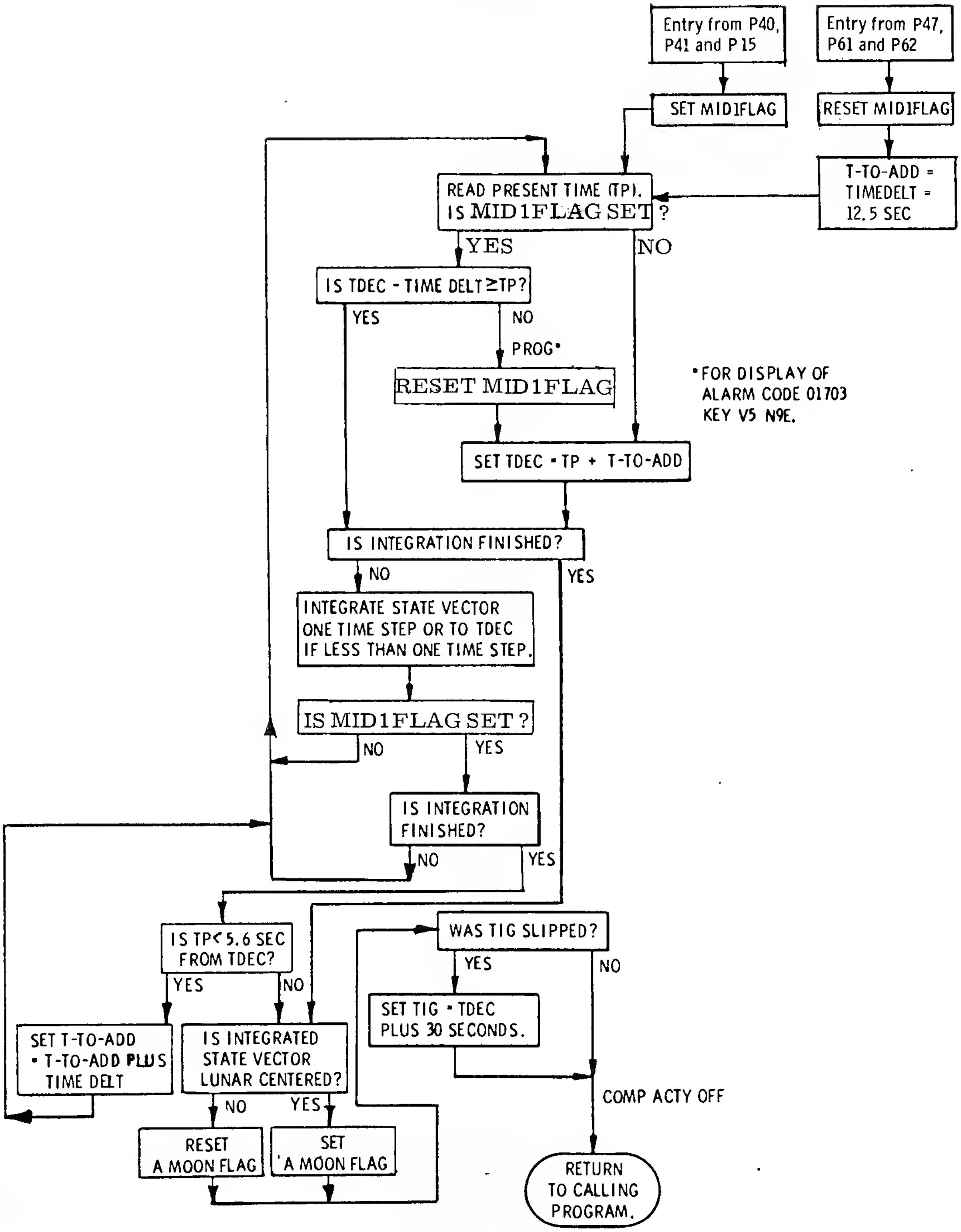

Figure 6.2.1-4. State Vector Integration Routine (CSM R41)

Alarm code 01301 may occur during R60. After verifying the alarm, the crew selects P52 to realign the IMU and then reselects P40.

Alarm code 01407 may occur during an SPS burn, indicating that the angle between $\underline{v}_G$ and the vector $(\underline{a}_T - \underline{b})$, used to compute T_{GO}, is greater than 90 deg. In effect, the alarm covers the logically possible, but pragmatically improbable, situation for which a negative time (i.e., past time) to cutoff would be indicated. Crew procedures should be consulted about recovery.

Alarm code 01703 may occur during R41 of P40. After verifying the alarm, the crew will note a discontinuity in the contents of DSKY R1 (i.e., time from t_{IG}). The value on the Digital Event Timer will no longer be valid. No crew action is necessary.

6.2.1.7 Restarts

Should a hardware restart occur during P40, the RESTART light would go on. A hardware or software restart occurring during an automatic attitude maneuver, R60, will terminate this routine. The crew can recover by keying PRO to the flashing VERB 50 NOUN 18 that returns to the DSKY after the restart.

6.2.2 P41, Reaction Control System (RCS) Maneuver — CMC

P41, one of the powered flight guidance programs, can be used to handle the timing of short, manually controlled RCS burns whenever a change-of-orbit maneuver is required. During these burns, P41 maintains the CSM state vector, controls spacecraft attitude—to achieve the desired velocity at the end of the maneuver—and provides the crew with a monitor of the maneuver's progress.

P41 uses the AVERAGEG routine for state vector updating and the steering routines (i.e., Lambert Aimpoint or External $\Delta \underline{v}$) to compute DSKY displays. (Refer to subsection 6.1.)

The crew's first choice about a powered flight maneuver must be which of the powered flight programs to use. When a GNCS-controlled maneuver is desired, the choice of program usually depends on the magnitude of velocity-to-be-gained (i.e., on the amount of energy required to accomplish the maneuver). P41 is chosen if $|\underline{v}_G|$ is less than,

$$\frac{F_{SPS}}{m} \cdot \Delta t_{MIN}$$

In the above expression, F_{SPS} is the thrust of the SPS engine (about 20,500 lb), m is the mass of the total vehicle (including the LM if it is attached), and Δt_{MIN} is the minimum burn time for which the particular SPS engine being considered has been successfully tested. Currently, Δt_{MIN} equals 0.5 sec. The maximum $|\underline{v}_G|$ that can be acquired by an RCS burn (P41) can be determined by:

$$\left|\underline{v}_G\right| = \frac{w_{prop}}{w_{tot}} \; g_E \; ISP_{RCS}$$

where w_{prop} is the weight of RCS fuel available, w_{tot} is the total weight of the vehicle, g_E is gravitational acceleration at the earth's surface, and

$$ISP_{RCS} = \frac{F_{RCS}}{\dot{w}_{prop}} = 276.45 \text{ sec}$$

A prethrust program, P3x, establishes the parameters needed for thrust control guidance. After the appropriate P3x has been performed, the astronaut must not select another P3x, P7x, or P23 before the burn. These programs use some of the same variable computer storage locations and would destroy the thrusting parameters established by the original P3x for this burn. Since mark incorporation would change the current state vector without correspondingly changing the thrusting parameters, VHF or Optics marks should not be accepted in P20 (Options 0 and 4) between P3x and P41. If P20 had been previously selected, however, it may continue to run in the background. (The mark incorporation function is turned off by P3x.)

6.2.2.1 P41 Procedures

Tables 6.2.2-I and -II show P41 displays and extended verbs, respectively. Figure 6.2.2-1 is a flowchart of P41.

Before entering P41, the Autopilot Data Load Routine (R03) and a prethrust program (P3x) must be performed. In addition, the IMU must be powered up and aligned.

Upon selection—either by the crew or by the MINKEY controller—P41 performs the IMU Status Check Routine (R02) and illuminates the PROG light if the ISS is off (alarm code is 00210) or if the IMU orientation is not known (alarm code is 00220). P41 then computes the initial thrust direction and the preferred attitude matrix.

At the completion of R02, the program enters the Attitude Maneuver Routine (R60), flashes VERB 50 NOUN 18, and displays the desired gimbal angles to 0.01 deg in the registers as follows:

R1 = OGA, roll
R2 = IGA, pitch
R3 = MGA, yaw.

The crew has the option of performing (i.e., keying PRO) or bypassing (i.e., keying ENTR) this maneuver in P41. If the PROG light goes on at this point and the alarm code is 01301, the desired gimbal angles are indeterminate because the initial $\underline{y}_G$ is collinear with the stable member y-axis. A maneuver to the desired attitude would produce gimbal lock.

If the yaw angle is not small enough to avoid approaching gimbal lock, the crew can select P52 to do the required preferred realignment. If the yaw angle is small enough, the crew can perform the attitude maneuver automatically or manually. If

TABLE 6.2.2-I

DISPLAYS ASSOCIATED WITH P41 (CSM)

DSKY	Initiated by	Purpose	Condition	Register
V05 N09E	Astronaut	Verify PROG alarm	00205 Bad PIPA reading detected 00210 ISS not on 00220 IMU orientation unknown 01301 arc-sine or arc-cosine argument too large 01703 time of ignition slipped	R1 xxxxx R2 xxxxx R3 xxxxx *
FL V50 N18	R60	Display required gimbal angles	OGA - roll IGA - pitch MGA - yaw	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
V06 N18	R60	Display of final gimbal angles	OGA IGA MGA	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
FL V16 N85	P41	Display remaining $\underline{v}_G$	Components of $\underline{v}_G$	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V16 N44	R30	Display orbital parameters	Apogee altitude Perigee altitude Time of free fall	R1 xxxx.x n. mi. R2 xxxx.x n. mi. R3 xxBxx min,sec
V06 N85	P41	Display $\underline{v}_G$	Three components of $\underline{v}_G$ to be acquired, in control coordinates	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V16 N54	R31	Display	Range Range rate Theta	R1 xxx.xx n. mi. R2 xxxx.x ft/sec R3 xxx.xx deg

* The alarm codes are displayed as follows:

R1 = First alarm following error reset
R2 = Second alarm following error reset
R3 = Most recent alarm.

TABLE 6.2.2-II

EXTENDED VERBS FOR USE WITH P41 (CSM)

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters	DSKY displays apogee, perigee, and time of free fall
83 ENTR	Do R31	Display rendezvous parameters	DSKY displays range, range rate and theta, the angle between local horizontal and the spacecraft X-axis

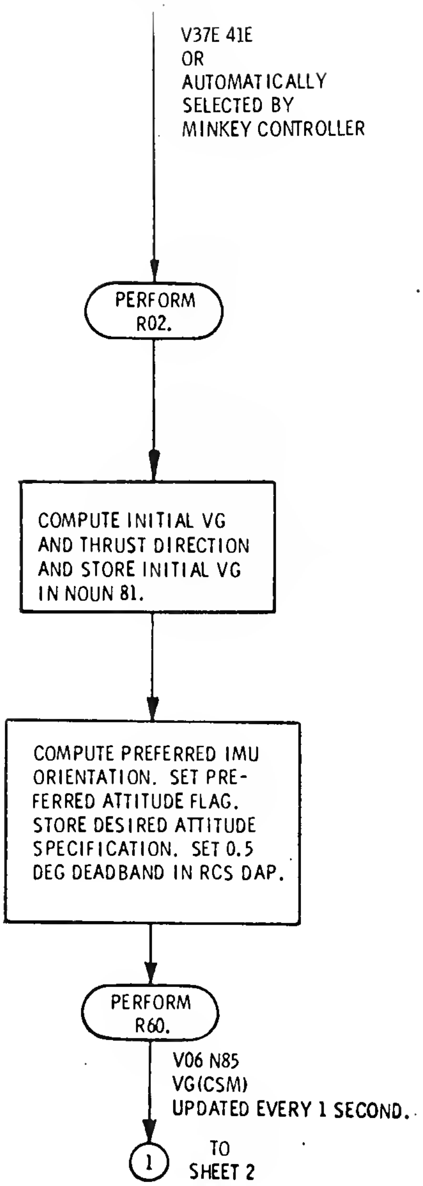

Figure 6.2.2-1. RCS Manuever Program (CSM P41) (Sheet 1 of 2)

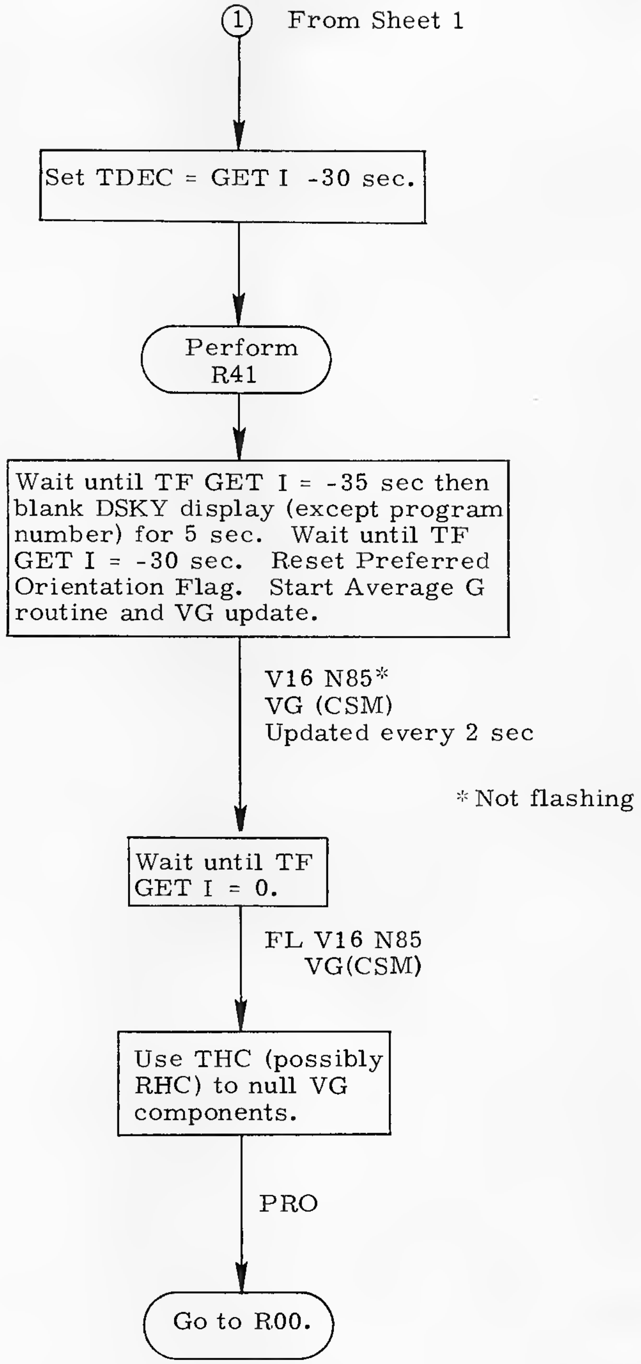

Figure 6.2.2-1. RCS Maneuver Program (CSM P41) (Sheet 2 of 2)

the maneuver is performed by the autopilot, the crew places the SC CONT switch in CMC, the CMC MODE switch in AUTO, and then keys PRO to VERB 50 NOUN 18, signaling the RCS DAP to begin the maneuver via R60.

During the maneuver, a non-flashing VERB 06 NOUN 18 displays the final gimbal angles, and the crew monitors the maneuver on the FDAI ball and needles. If gimbal lock is approached, or if the entire maneuver is done manually, the crew uses the RHC to complete the maneuver. (Once the RHC is removed from detent, the automatic maneuvering routine ceases and can be reinitiated only by keying PRO in response to the flashing VERB 50 NOUN 18.) A VERB 50 NOUN 18 display occurs upon completion of the R60 maneuver. To exit from R60, the crew keys ENTR in response to VERB 50 NOUN 18.

Upon completion (or termination) of R60, the DSKY displays (and repeats every second) VERB 06 NOUN 85; the three registers contain the three components of $\underline{v}_G$, in control coordinates. The total velocity to be acquired during the maneuver is displayed and decreases when the maneuver begins. Nominally, the crew places SC CONT in CMC and CMC MODE in AUTO or HOLD.

The program at this time enters the State Vector Integration Routine (R41) which integrates the CSM state vector ahead to t_{IG}-30 seconds. If R41 cannot be completed before t_{IG}-42.5, a program alarm (code 01703) is generated and the time of ignition is slipped. R41 is explained in more detail in paragraph 6.2.1.5.2.

At t_{IG}-35, the DSKY is blanked for 5 seconds, then the VERB 16 NOUN 85 display will start to monitor the same register data. If $\underline{v}_G$ updating is being executed in the External $\Delta\underline{v}$ mode, a change of more than 0.4 ft/sec in any component during the period t_{IG}-30 to t_{IG} indicates excessive PIPA bias.

At t_{IG}, the program flashes VERB 16 NOUN 85. The crew, using the RHC and THC, should null the velocity-to-be-gained to a value specified in the checklist. Upon completion of thrusting, the crew keys PRO to end major mode P41.

The crew may select the Orbital Parameters Display (VERB 82 ENTR) to check apogee altitude, perigee altitude, and time of free-fall. If R2—showing perigee altitude—is greater than 49.4 n. mi. (near earth) or 5.8 n. mi. (near the moon), R3—showing time of free-fall—should read minus 59 minutes 59 seconds. The crew keys PRO to return to the flashing VERB 37 displays.

The crew can key VERB 83 ENTR to monitor the range, range rate, and the angle between local horizontal and the spacecraft X-axis.

AVERAGEG will continue running until a new major mode is selected. Therefore, immediate new-mode selection is imperative to avoid accumulation of PIPA bias errors.

6.2.2.2 Timelines

The timelines shown in Figure 6.2.2-2 relate the program flowchart to crew observance and response.

6.2.2.3 Alarms

The alarm codes which may occur in P41 are listed below and a detailed explanation of each follows:

a. Alarm code 00205 occurs when a bad PIPA reading is detected.
b. Alarm code 00210 occurs if the ISS is not on.
c. Alarm code 00220 occurs if the IMU orientation is not known.
d. Alarm code 01301 occurs if the arc-sine or arc-cosine argument is too large.
e. Alarm code 01703 occurs if the time of ignition is slipped.

Alarm code 00205 may occur during the thrusting maneuver. The maneuver should then probably be terminated since the display and AVERAGEG state vector maintenance will no longer be valid.

Alarm code 01301 may occur during R60. After verifying the alarm (i.e., keying in VERB 05 NOUN 09 ENTR) the crew should select P52 to realign the IMU. Then P41 may be reselected.

For a detailed explanation of the occurrence of alarm codes 00210 and 00220 and 01703, refer to paragraph 6.2.1.6.

6.2.2.4 Restarts

Should a hardware restart occur during P41, the RESTART light on the DSKY will be illuminated. A hardware or software restart will terminate the automatic attitude maneuver (R60). The crew can recover by keying PRO in response to the flashing VERB 50 NOUN 18 that returns to the DSKY after the restart.

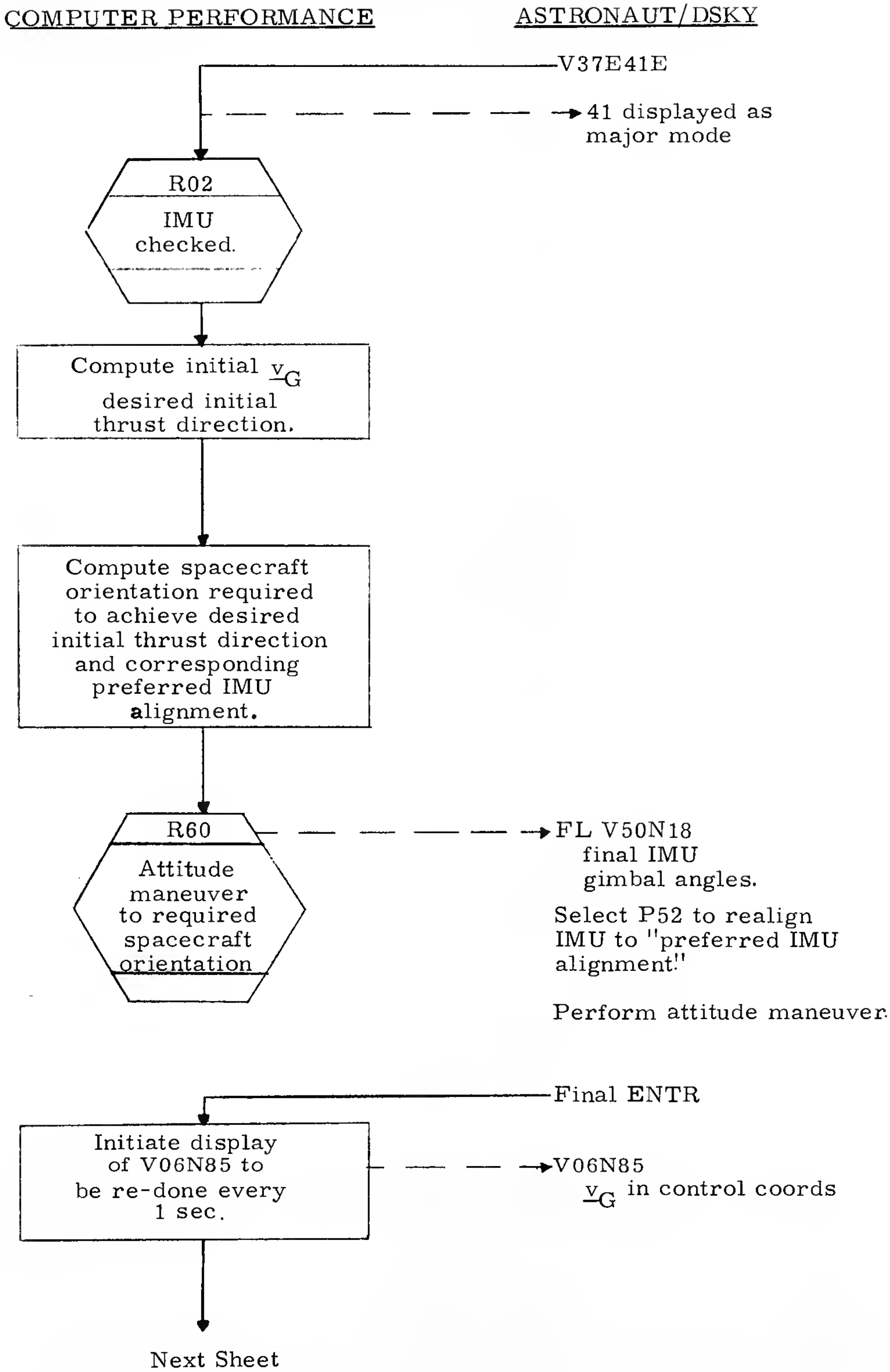

Figure 6.2.2-2. Timelines of RCS Maneuver Program (CSM P41)
(Sheet 1 of 2)

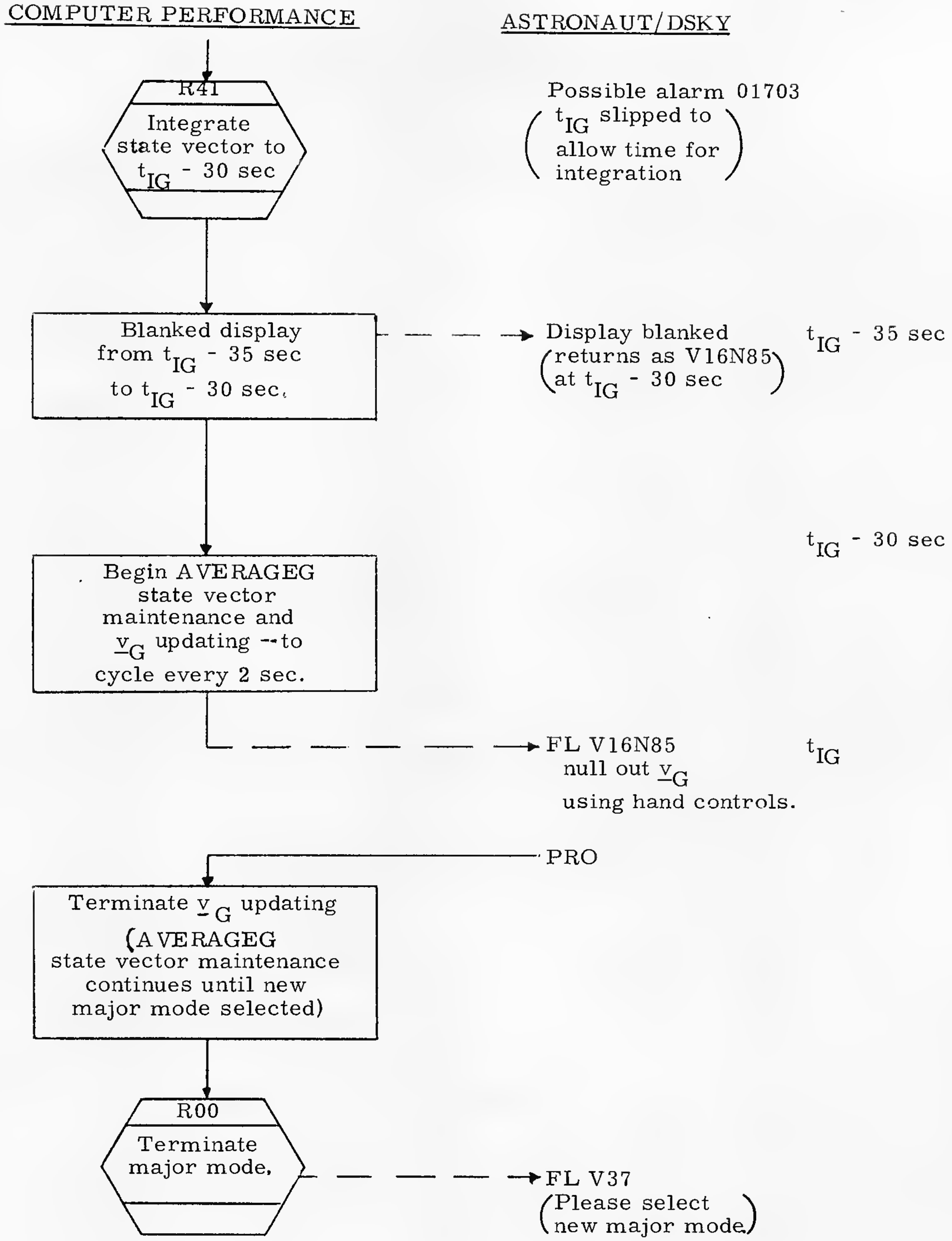

Figure 6.2.2-2. Timelines of RCS Maneuver Program (CSM P41) (Sheet 2 of 2)

6.2.3 P47, Thrust Monitor—CMC

P47, the powered flight monitor program, maintains the CSM state vector during a thrusting maneuver not controlled by the GNCS and provides a monitor of the maneuver's progress for the crew. For example, the translunar insertion (TLI) maneuver is done using the SIVB;* the final docking maneuver in rendezvous is done using THC manual control; in case of an SPS engine failure during the second lunar orbit insertion (LOI2) maneuver, or late in the first lunar orbit insertion (LOI1) maneuver (when enough fuel has been used to make a sufficiently light vehicle), the LM DPS or APS engine can be used to initiate a return to earth.

The program uses the AVERAGEG routine for state vector updating. (For an explanation of AVERAGEG use, refer to subsection 6.1.)

6.2.3.1 P47 Procedures

Tables 6.2.3-I and -II present the displays and extended verbs associated with P47. Figure 6.2.3-1 is the program flowchart. Before entering P47, the CMC and the IMU must be on and aligned.

Upon selection of P47, shortly before t_{IG}, the program performs the IMU Status Check Routine (R02) and illuminates the PROG light if the ISS is off (i.e., alarm code is 00210) or the IMU orientation is unknown (alarm code is 00220).

At the completion of R02, the program enters the State Vector Integration Routine (R41), which integrates the CSM state vector ahead to the time that the AVERAGEG routine is turned on by the program. (Refer to paragraph 6.2.1.5.2 for a description of R41.)

The DSKY displays a flashing VERB 16 NOUN 83 with the three components of acquired Δv, in control coordinates. The registers contain zeros initially; the contents are updated every 2 seconds.

While the thrusting maneuver is performed, the crew must monitor the FDAI ball to avoid gimbal lock. If the PROG light goes on during the maneuver, the occurrence

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*Because of modifications to P15 for Colossus 3, increasing the amount of information available during this program, the crew will no longer need P47 information at this time.

TABLE 6.2.3-I

DISPLAYS ASSOCIATED WITH P47 (CSM)

DSKY	Initiated by	Purpose	Condition	Register
V05 N09E	Astronaut	Verify PROG alarm	00205 Bad PIPA reading detected 00210 ISS not on 00220 IMU orientation unknown	R1 xxxxx R2 xxxxx R3 xxxxx*
FL V16 N83	P47	Display $\Delta \underline{v}$ acquired	Three components in control coordinates	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec
FL V16 N44	R30	Display orbital parameters	Apogee altitude Perigee altitude Time of free fall	R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxxmin,sec
FL V16 N54	R31	Display	Range Range rate Theta	R1 xxx. xx n. mi. R2 xxxx. x ft/sec R3 xxx. xx deg
FL V16 N53	R34	Display	Range Range rate Phi	R1 xxx. xx n. mi. R2 xxxx. x ft/sec R3 xxx. xx deg
V16 N62E	Astronaut	Display	Velocity Rate of altitude change Altitude	R1 xxxxx. ft/sec R2 xxxxx. ft/sec R3 xxxx. x n. mi.

* The alarm codes are displayed as follows:

R1 = First alarm following error reset
R2 = Second alarm following error reset
R3 = Most recent alarm

TABLE 6.2.3-II

EXTENDED VERBS FOR USE WITH P47 (CSM)

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters	DSKY displays apogee, perigee, and time of free fall
83 ENTR	Do R31	Display first set of rendezvous parameters	DSKY displays range, range rate and theta, the angle between local horizontal and the spacecraft X-axis
85 ENTR	Do R34	Display second set of rendezvous parameters	DSKY displays range, range rate and phi, the angle between local horizontal and the sextant SLOS

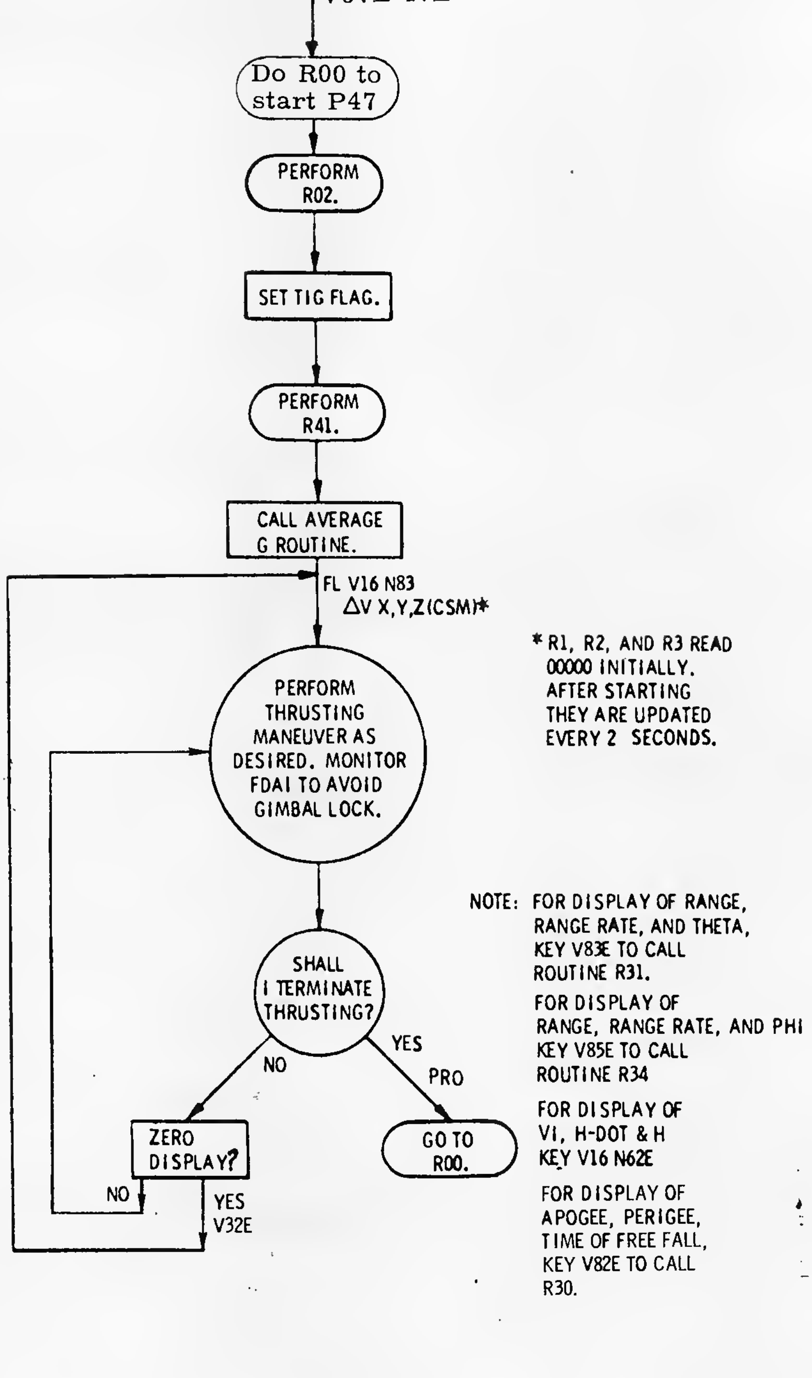


Figure 6. 2. 3-1. Thrust Monitor Program (CSM P47)

of an alarm code 00205 indicates the detection of a bad PIPA reading. If the crew wishes to recycle the display (zeroing the registers), VERB 32 ENTR can be keyed.

To terminate major mode P47, the crew keys PRO. The DSKY then flashes VERB 37, requesting the selection of a new major mode. It is important to respond to this immediately to terminate AVERAGEG and thus avoid accumulation of PIPA bias errors.

6.2.3.2 Time Lines

The time lines shown in Figure 6.2.3-2 relate the program flowchart to crew observance and response.

6.2.3.3 Alarms

The PROG alarm codes associated with P47 are listed below. A detailed description of each follows.

a. Alarm code 00205 occurs if a bad PIPA reading is detected.
b. Alarm code 00210 occurs if the ISS is not on.
c. Alarm code 00220 occurs if the IMU orientation is not known.

Alarm code 00205 may occur during the thrusting maneuver. The maneuver should be terminated since the display and AVERAGEG state vector maintenance will no longer be valid.

For detailed explanations of alarm codes 00210 and 00220, refer to paragraph 6.2.1.6.

6.2.3.4 Restarts

Should a hardware restart occur, the RESTART light on the DSKY would be illuminated; no other effect would be noticed by the crew.

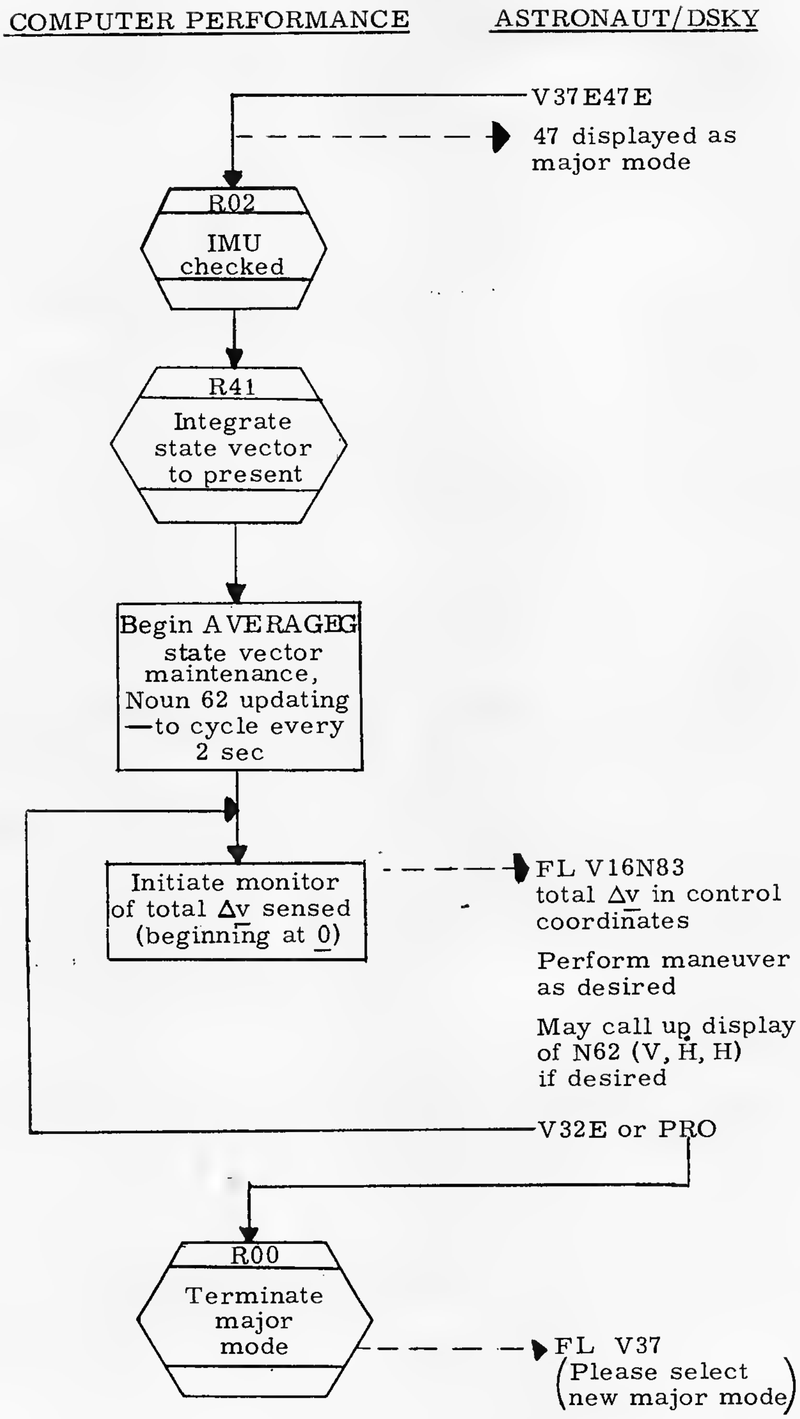


Figure 6.2.3-2. Timelines of Thrust Monitor Program (CSM P47)

6.3 LGC POWERED-FLIGHT PROGRAMS

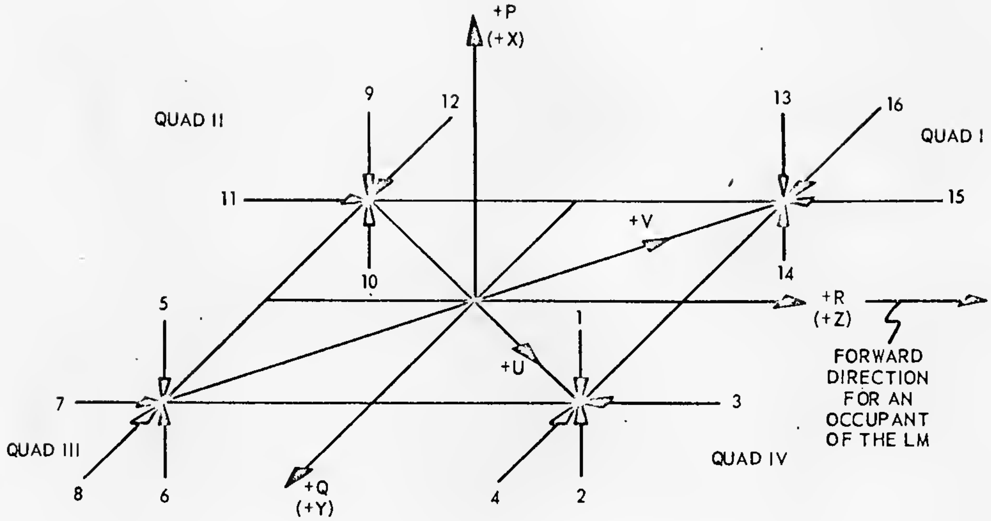
The Lunar Guidance Computer (LGC) has a program that monitors thrust (P47) and three programs that control thrust—P40 for DPS maneuvers, P41 for RCS maneuvers, and P42 for APS maneuvers. The cross-product steering cycle, which generates steering commands in P40 and P42, is discussed in subsection 6.1. The digital autopilot (DAP) implements these commands. The LM DAP is described in detail in Section 3 of the Luminary GSOP.

The LM DAP is designed to control attitude and translation for three vehicle configurations—LM descent, LM ascent, and CSM-docked. During powered flight the LM DAP controls the spacecraft attitude according to steering commands from the cross-product steering computations. In the LM descent configuration, control of the vehicle is achieved with the 16 jets of the RCS (as illustrated in Figure 6.3-1) and through the deflection of the throttleable, gimbaled DPS engine. Since the LM ascent stage has a fixed, constant-thrust engine installed near the centerline of the ascent stage, attitude control in the ascent stage is provided by the RCS jets.

Every two seconds, the steering computations compute a new desired attitude. An interface routine between the LM DAP and the guidance equations issues the rotation rate commands to bring the measured thrust direction into alignment with the desired thrust direction.

The LM DAP uses two trim-gimbal control algorithms for gimbaling the descent engine: attitude control algorithm and acceleration nulling control algorithm. Acceleration nulling control is used to trim the thrust direction so as to null the offset angular accelerations. The algorithm accomplishes this by keeping the thrust vector of the descent engine locked onto the shifting center of gravity of the LM. Attitude control is used to shift the thrust vector about the center of gravity to maintain full attitude control whenever the flight situation imposes only mild requirements on the LM DAP. The trim-gimbal drive directions are selected by the LGC to zero the attitude error, rate, and acceleration about each axis simultaneously. When the trim-gimbal control system uses the attitude control algorithm, the U and V RCS jets (as shown in Figure 6.3-1) are ordinarily inactive.

An initial alignment of the descent engine reduces the attitude transient caused by thrust offsets at ignition. At the end of the burn, the trim-gimbal drives are turned off, leaving the engine thrust axis approximately aligned through the center of gravity. For subsequent ignitions with the same vehicle configuration, realignment is not necessary.



KEY

JETS ASSOCIATED WITH RCS FUEL SYSTEM A (JETS 2, 4, 5, 8, 10, 11, 13, AND 15)

JETS ASSOCIATED WITH RCS FUEL SYSTEM B (JETS 1, 3, 6, 7, 9, 12, 14, AND 16)

NOTES:

1. THE ARROWS INDICATE THRUST DIRECTION, NOT EXHAUST VELOCITY.
2. SEE FIG. 3.1-5, GSOP FOR THE RELATIONSHIP OF THE RCS JETS AND CONTROL AXES DEPICTED HERE TO THE LM VEHICLE.
3. IN CASE OF FAILED JETS, THE ASTRONAUT DISABLES JETS IN PAIRS AS FOLLOWS:

1,3	5,8	9,12	13,15
2,4	6,7	10,11	14,16

4. THE P, Q, AND R DESIGNATIONS FOR THE CONTROL AXES ARE USED IN CONNECTION WITH ROTATION, WHEREAS THE X, Y, AND Z DESIGNATIONS ARE USED IN CONNECTION WITH TRANSLATION.

Figure 6.3-1. The 16 Jets of the RCS and Their Thrust Directions

During powered flight, the LM mass is decremented every two seconds according to the measured velocity change and the assumed main-engine specific impulses. The mass-dependent control gains are then recomputed as a function of the decremented mass. Since the mass properties of the vehicle are continually changing, the LM DAP using the automatic mass-update method should maintain reasonable estimates during the varying conditions of powered flight.

Operation of the LM DAP during powered flight can be completely automatic, requiring no crew inputs. Before the burn, however, the crew can enter control parameters via the DAP Data Load Routine (R03). Refer to paragraph 9.3.1. During a docked-DPS maneuver, in order to prevent excessive thermal impingement of the U and V RCS jet plumes upon the vehicle, the crew keys VERB 65 ENTR into the DSKY to inhibit RCS control about the U- and V-axes; control is maintained by the trim-gimbal system in the Attitude Control mode.

The performance of the LM DAP can be monitored by calling (via VERB 61) the Mode I displays on the FDAI attitude-error needles. Mode I displays the difference between current CDU angles desired and the actual CDU angles. The usual FDAI display is Mode II, the difference between the desired gimbal angles (stored in NOUN 22) and the actual gimbal angles. The Mode II display is selected manually at the beginning of R60, and can be selected manually via VERB 62. Both Mode I and Mode II errors are in body axes. The displays are updated every 0.2 sec unless the PGNS Mode Control switch is off or the IMU CDU's are not usable.

BLANK

6.3.1 P40, Descent Propulsion System Maneuver—LGC

The powered flight guidance program, P40, coordinates the timing of some Descent Propulsion System (DPS) maneuvers, maintains the LM state vector; controls the thrust direction–so as to achieve the desired velocity at the end of the maneuver; and provides the crew with a monitor of the maneuver's progress.* The LM P40 behaves much like the CSM P40. (Refer to paragraph 6.2.1.)

The descent engine is gimbaled for thrust vector control. The PGNCS automatically issues on and off commands and gimbal drive actuator commands to the descent engine. The automatic on and off commands can be overridden manually.

Several limitations exist on the use of the DPS engine. Some of these limitations are listed and discussed here, though the following list is not exhaustive.**

a. The descent engine must not be started more than 20 times.

b. The first descent engine firing must last at least 30 seconds to ensure full pressurization of the ullage space in the propellant tanks.

c. Normal throttle profile for all descent engine starts is at 10 percent throttle setting for 26 seconds—a nominal value that can be changed (by the crew, if necessary)—to permit corrective gimbaling without introducing large attitude transients or possible loss of control because the thrust vector at engine start may not be directed through the LM center of gravity.

d. The landing gear must be deployed before descent engine firing. If the landing gear is not deployed, it will be in the path of the descent engine plume and will be damaged.

A targeting program, P3x, will establish the parameters needed for thrust control guidance. After the appropriate P3x has been performed, the astronaut must not select another P3x, P7x or P47 before the burn. These programs use some of the same variable computer storage locations and would destroy the thrusting parameters established by the original P3x for this burn.

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* The DPS Maneuver Program is not used during powered descent or during P70, the DPS Abort Program.

** A more complete list can be found in the APOLLO Operations Handbook, Lunar Module, Volume I, Document No. LMA790-3-LM5.

P40 uses the AVERAGEG routine for state vector updating and cross-product steering for guiding the thrust direction. AVERAGEG and cross-product steering are discussed in subsection 6.1.

6.3.1.1 P40 Procedures

Tables 6.3.1-I and -II show P40 displays and extended verbs, respectively. Figure 6.3.1-1 is the program flowchart. Before entering P40, the following must be performed:

a. LGC turned on
b. R03, Autopilot Data Load Routine
c. P3x, a prethrust program
d. ISS on for at least 15 minutes
e. IMU at a known orientation.

Crew procedures specify how long before DPS ignition the crew must select P40, via the DSKY, to allow sufficient time for performing the necessary routines before ignition. P40 first checks for the presence of the DPS. If the DPS has been staged, the DSKY will flash VERB 05 NOUN 09 and display alarm code 01706. The crew can respond by keying in VERB 34 ENTR to terminate P40.

The program next enters the IMU Status Check Routine (R02), as in the CSM P40. Upon completion of R02, the program computes the initial thrust direction of $\underline{v}_G$, and the preferred IMU orientation, and then enters the Attitude Maneuver Routine (R60). This routine is similar to the CSM R60 (refer to paragraph 6.2.1.3) except that the PGNS MODE CONTROL switch (on the STAB/CONT panel) is in the AUTO position for an automatic maneuver the NOUN 18 display shows FDAI angles rather than gimbal angles, and there is no nonflashing VERB 06 NOUN 18 display during the maneuver. There is a possibility of a 01301 alarm during the maneuver if the arc-sine or arc-cosine argument is too large. Alarm 00401 indicates that the final gimbal angles would be in gimbal lock.

Upon completion (or termination) of R60, the program checks whether the GUID CONT switch has been set to PGNS, the PGNS MODE CONTROL switch to AUTO, and the THR CONT switch to AUTO. If these settings have not been made, the DSKY flashes VERB 50 NOUN 25 with R1 containing 00203. If the crew prefers not to select these modes during the thrusting maneuver, it can key ENTR. Otherwise, the crew can place the GUID CONT switch in the PGNS position, the PGNS MODE CONTROL switch to AUTO, the THR CONT switch to AUTO, and key PRO.

TABLE 6.3.1-I

DISPLAYS ASSOCIATED WITH P40 (LM) (SHEET 1 OF 2)

DSKY	Initiated by	Purpose	Condition		Registers
			Alarm Code	Condition	
V05 N09E	Astronaut	Verify PROG alarm	00210 00220 00401 01301 01407 01703	IMU not on IMU orientation unknown Desired gimbal angles yield gimbal lock Arc sine or arc cosine argument too large v_G increasing t_{IG} slipped	R1 xxxxx * R2 xxxxx R3 xxxxx
FL V05 N09	P40	Display alarm	01706	DPS staged	R1 xxxxx * R2 xxxxx R3 xxxxx
FL V50 N18	R60	Display FDAI angles; request maneuver	FDAIX - roll FDAIY - pitch FDAIZ - yaw		R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
FL V50 N25	P40	Switch to PGNCS automatic mode. Make the following switch selections: GUID CONT→ PGNS PGNS MODE CONTROL → AUTO THR CONT → AUTO (Refer to Text)	00203 — checklist code		R1 00203

* The alarm codes are displayed as follows:
R1 = First alarm following error reset
R2 = Second alarm following error reset
R3 = Most recent alarm

Refer to note in paragraph 3.3.1-6

TABLE 6.3.1-I

DISPLAYS ASSOCIATED WITH P40 (LM) (SHEET 2 OF 2)

DSKY	Initiated by	Purpose	Condition	Registers
V06 N40	P40	Display	Time from t_{IG} v_G magnitude Sum of acquired velocity	R1 xxBxx min, sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec
FL V99 N40	P40	Request DPS engine-on enable	---	---
FL V97 N40	R40	Low thrust detected	---	---
FL V16 N40	P40	Display final values	Time from cutoff at last cycle Remaining v_G magnitude Sum of acquired velocity	R1 xxBxx min, sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec
FL V16 N85	P40	Display remaining $\underline{v}_G$	Components of $\underline{v}_G$ in LM body axes	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec
V06 N86E	Astronaut	On call display of $\underline{v}_G$	$\underline{v}_G$ components in local vertical co-ordinates	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec

TABLE 6.3.1-II

EXTENDED VERBS FOR USE WITH P40 (LM)

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters (apogee, perigee, time of free fall)	FL V16 N44 R1 xxxx. x n. mi. R2 xxxx. x n. mi. R3 xxBxx min, sec
83 ENTR	Do R31	Display rendezvous parameters (range; range rate; theta, the angle between local horizontal and the LM +Z-axis)	FL V16 N54 R1 xxx. xx n. mi. R2 xxxx. x ft/sec R3 xxx. xx deg

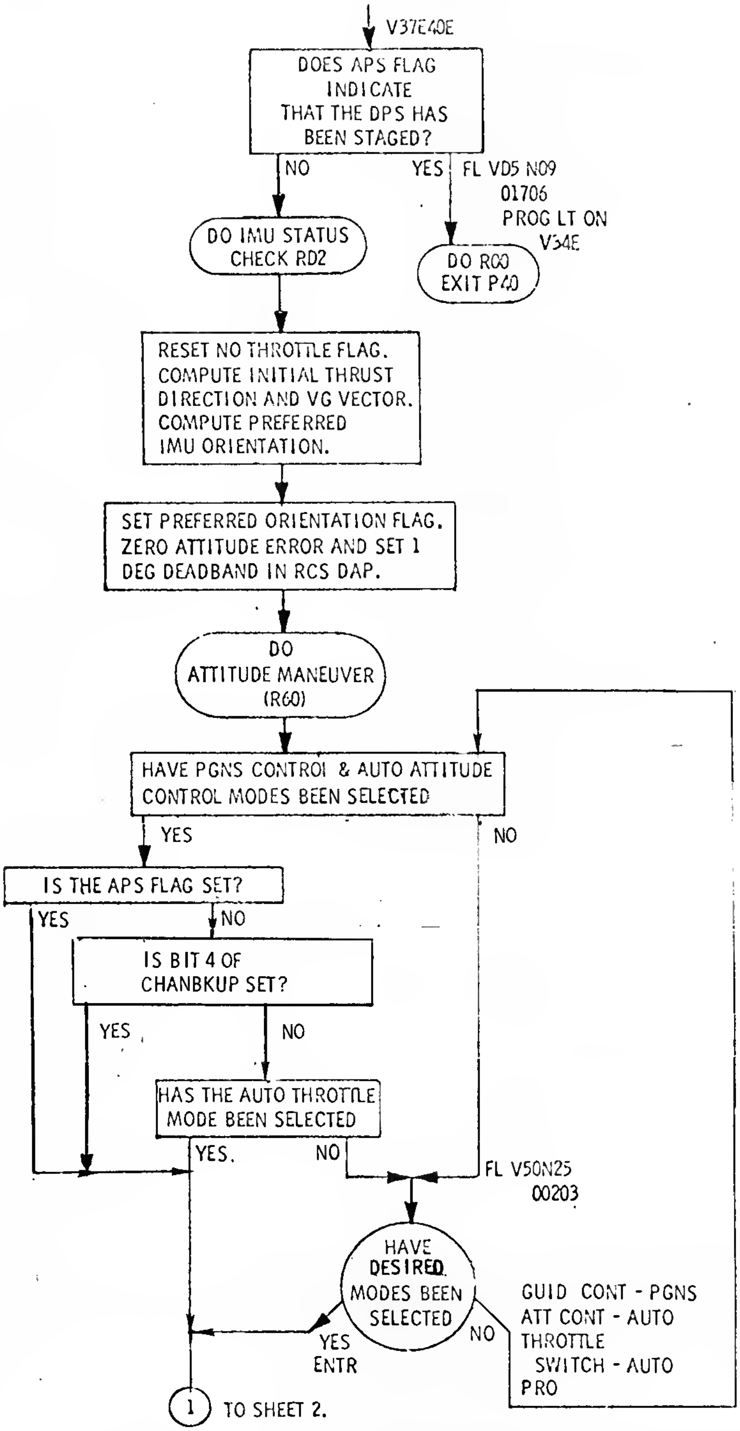

Figure 6.3.1-1. DPS Maneuver Program (LM P40) (Sheet 1 of 4)

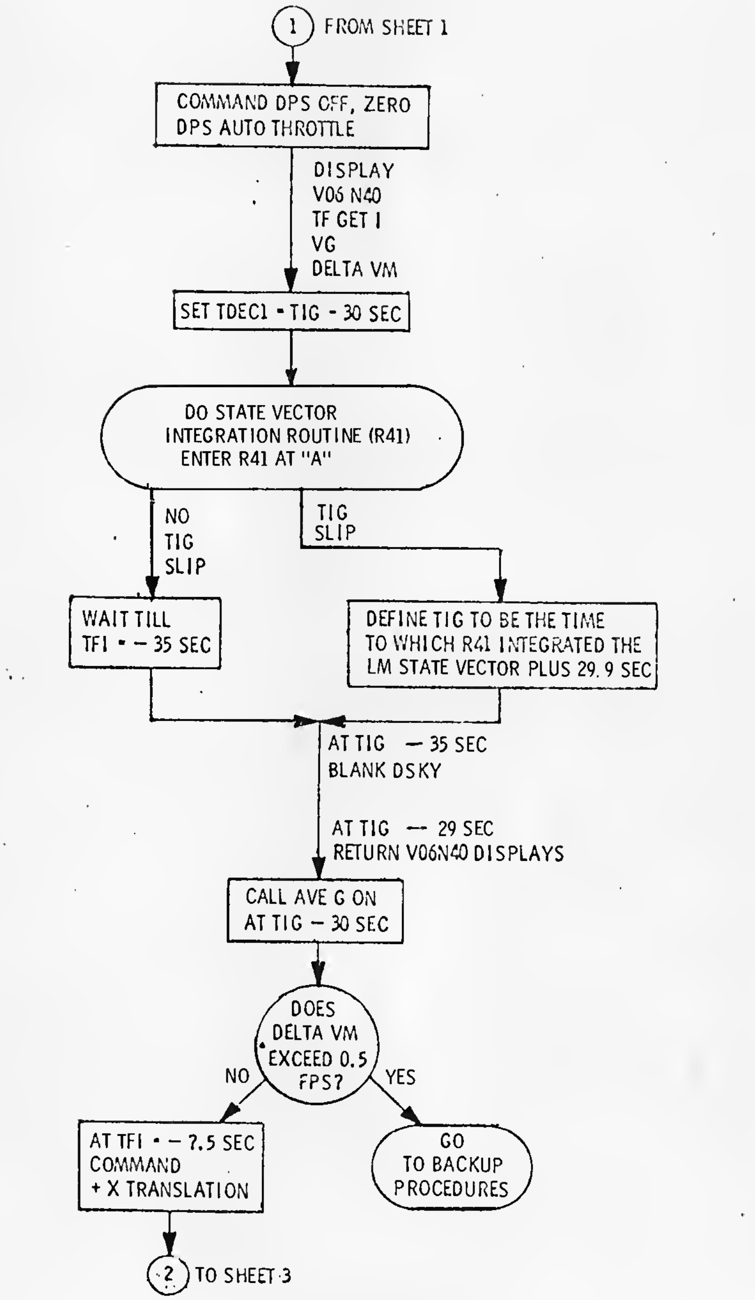

Figure 6.3.1-1. DPS Maneuver Program (LM P40)
(Sheet 2 of 4)

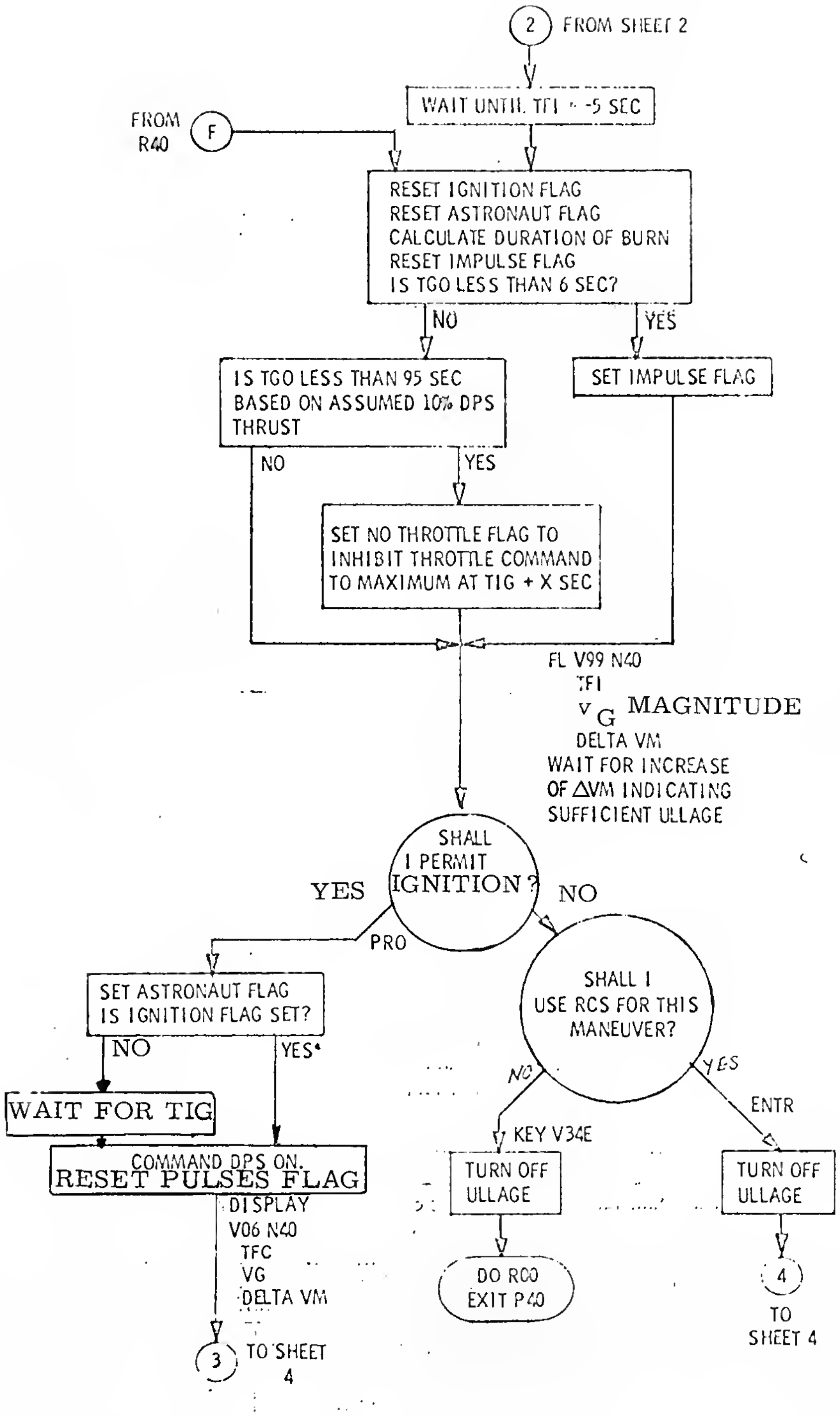

Figure 6.3.1-1. DPS Maneuver Program (LM P40)(Sheet 3 of 4)

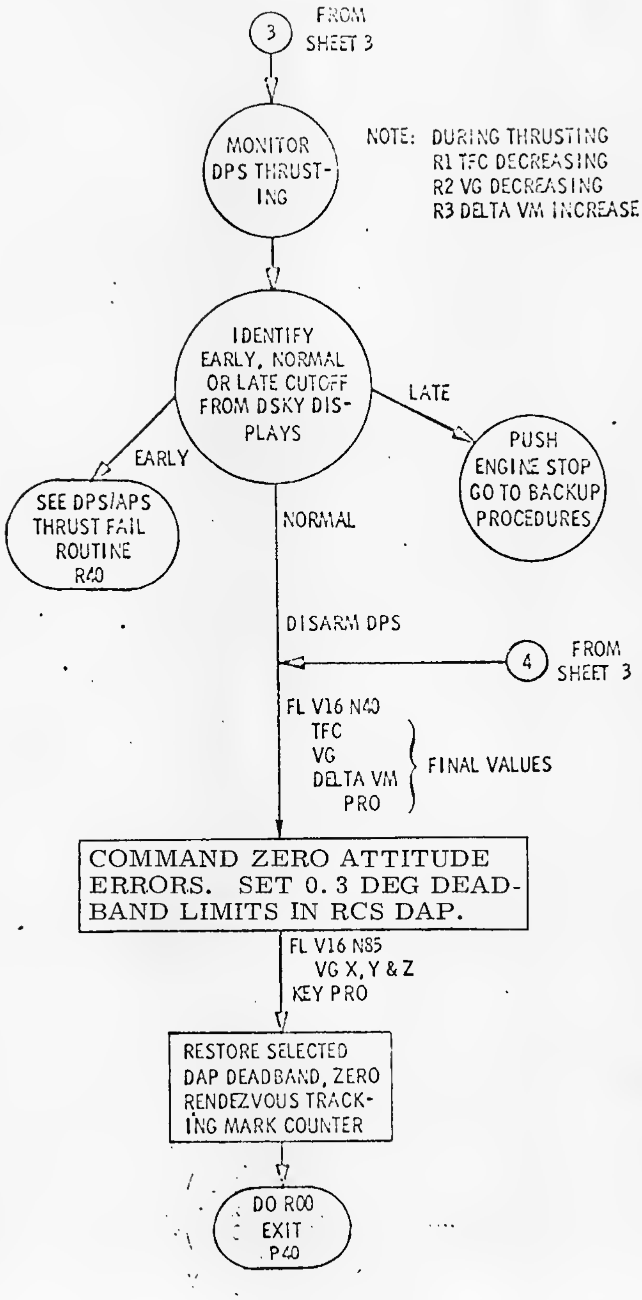

Figure 6.3.1-1. DPS Maneuver Program (LM P40) (Sheet 4 of 4)

NOTE.—Appearance of a VERB 50 NOUN 25 display in spite of crew verification of correct switch setting indicates a channel-bit failure. The recommended procedure is to communicate with ground for proper procedure to follow. If the display appears because the auto-discrete has failed, and if ground communication not feasible, the crew can key in R03 and load a value of one into the D position of R2 in the VERB 04 NOUN 46 display.

Next, the program commands the DPS off, zeros the DPS auto throttle and displays VERB 06 NOUN 40, with the registers containing the following:

R1 = time from DPS ignition

R2 = magnitude of velocity-to-be-gained (v_G)

R3 = magnitude of Δv.

The program next enters the State Vector Integration Routine (R41), which integrates the LM state vector ahead to t_{IG} -30 seconds. During R41, the COMP ACTY light illuminates; the other visible sign that R41 is running is a possible alarm code 01703 indicating that t_{IG} has been slipped to allow sufficient time to complete integration. Should this alarm occur, the new value of t_{IG} will be used for the time-from-ignition displayed in R1 of VERB 06 NOUN 40 after integration has been completed. Next, the crew will verify or set the thrust translation controller (TTCA) to the MIN THRUST position. The crew will arm the DPS and check the thrust indicator to be certain the auto throttle command is zeroed.

At t_{IG} -35 seconds the DSKY will be blank for 5 seconds. At t_{IG} -29 (R1 = -00B29), the VERB 06 NOUN 40 display will return, indicating the start of the AVERAGEG $\underline{v}_G$ update. For the next 15 seconds, the crew should watch R3 to see that it does not exceed 0.5 ft/sec, which would indicate excessive PIPA bias errors. If excessive PIPA errors are so indicated, the crew should go to backup procedures.

Ullage (that is, +X translation to force fuel to the back end of the tanks) begins at t_{IG} -7.5 seconds. At t_{IG} -5 seconds, the program flashes VERB 99 NOUN 40 to request "please perform engine-on enable." After sufficient ullage, as indicated by an increase in Δv (R3), the crew permits DPS ignition by keying PRO. To avoid the burn altogether—and not permit ignition—the crew can key VERB 34 ENTR, or complete the maneuver with the RCS jets by keying ENTR.

If the crew has chosen to permit ignition, the VERB 06 NOUN 40 display returns until t_{IG}. After ignition, R1 will contain the time from cutoff (TFC), which is initially calculated and displayed based on 10 percent DPS thrust. This display will count down with elapsed time until TVC steering is initiated, after which TFC is recalculated, based on actual thrust every 2 seconds by the guidance equations. The TFC display is updated every 1 second. If the burn is to be impulsive (i.e., less than 6 sec), it will be done with fixed engine gimbal angles. If TFC at ignition is less than 95 seconds, maximum throttle will not be commanded. The crew can identify early, normal, or late engine cutoff from assessment of DSKY displays. If engine cutoff is late, the crew can depress the engine STOP pushbutton and go to backup procedures. An early cutoff would be detected by the program, which would then transfer control to R40, the Thrust Fail Routine. After normal cutoff, the crew disarms the DPS.

The DSKY flashes VERB 16 NOUN 40 to request proceed. The crew can record the register values of VERB 16 NOUN 40 as desired and key PRO. The DSKY flashes VERB 16 NOUN 85 to request response and displays the components of the residual velocity-to-be-gained, resolved along the LM body axes. The $\underline{v}_G$ vector will be updated by the cross product steering during each 2-second computation cycle. The crew can use the TTCA to null the $\underline{v}_G$ components; after the maneuver is completed, the Orbital-parameters Display Routine (R30) can be selected (VERB 82 ENTR), to check for reasonable pericenter. To exit P40, the crew keys PRO in response to the flashing VERB 16 NOUN 85.

AVERAGEG will continue running until a new major mode is selected. Therefore, immediate new mode selection is imperative to avoid accumulation of PIPA bias errors.

6.3.1.2 Routines Associated with P40

6.3.1.2.1 DPS/APS Thrust Fail Routine.—The DPS/APS Thrust Fail Routine (R40) is automatically called during P40 and P42. Figure 3.3.1-1 gives a brief logical flow of R40. When low thrust (thrust below the minimum threshold value of each 2-second cycle) is detected, flashing VERB 97 NOUN 40 notifies the crew of the thrust fail. (No steering is present at this point.) The crew can verify LGC interpretation of thrust failure by keying PRO. To terminate the maneuver, the crew keys VERB 34 ENTR. To attempt to complete the burn, the crew keys ENTR returning control to P40 or P42.

The threshold value for the Δv comparison has the following values:

a. DPS with docked CSM = 12 cm/sec
b. DPS with LM alone = 36 cm/sec
c. APS with LM alone = 308 cm/sec

A more detailed explanation of R40 is given in paragraph 3.3.2.2.3.

6.3.1.2.2 State Vector Integration Routine.—Figure 6.3.1-2 is a flowchart of the State Vector Integration Routine (R41). R41 is automatically selected by P40, P41, P42, P47, P12, and P63. The purpose of this routine is to integrate the state vector ahead to the time that the AVERAGEG routine is turned on by the thrusting program. R41 allows 20 seconds in the LM for completion of integration as opposed to 12.5 seconds in the CSM. If the state vector integration cannot be completed before the specified time, a program alarm occurs (alarm code 01703) and the t_{IG} is slipped. P47 enters R41 at B and omits any specification of the time.

6.3.1.3 Alarms

A list of alarm codes that may occur in P40 follows, with a detailed description for remedying the alarms:

a. Alarm code 00210 occurs if the IMU is not operating.
b. Alarm code 00220 occurs if the IMU orientation is unknown.
c. Alarm code 00401 occurs if the desired gimbal angles would yield gimbal lock.
d. Alarm code 01301 occurs if an arc-sine or arc-cosine argument is too large.
e. Alarm code 01407 occurs if the velocity-to-be-gained is increasing.
f. Alarm code 01703 occurs if the t_{IG} is slipped.
g. Alarm code 01706 occurs if P40 is selected, but the DPS has been staged.

Alarm codes 00210 and 00220 may occur immediately after P40 calls the IMU Status Check Routine; they appear as PROG alarms on the DSKY. The crew must key VERB 05 NOUN 09 ENTR to identify the abnormality, depress KEY REL and RSET when the alarm is identified, and respond to flashing VERB 37.

Alarm code 00401 may occur during R60 if the computed desired gimbal angles would produce gimbal lock (i.e., $|MGA| \geq 70$ deg). The crew can maneuver if the maximum middle gimbal angle is less than 85 degrees, or the crew can realign the IMU.

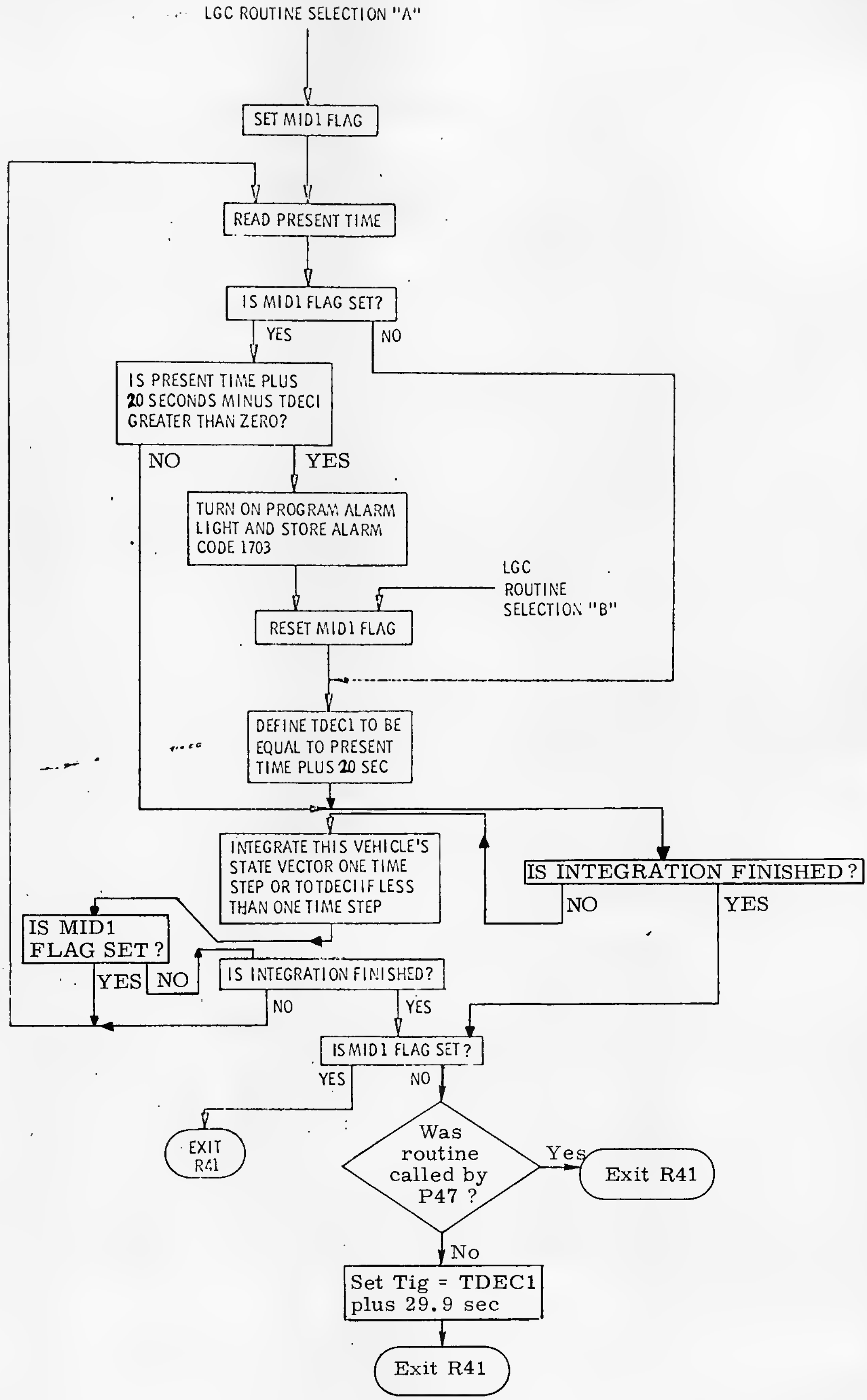

Figure 6.3.1-2. State Vector Integration Routine (LM R41)

Alarm code 01301 may also occur during R60. It is intended for testing and debugging and is not likely to occur in flight.

Alarm code 01407 may occur during thrusting. The crew should terminate thrusting and check orbital parameters.

Alarm code 01703 may occur during R41. After the COMP ACTY light goes out, the crew will note a discontinuity in the contents of DSKY R1 (i.e., time from t_{IG}). The value on the Digital Event Timer will no longer be valid. No crew action is necessary unless called for by mission procedures.

Alarm code 01706 is a main alarm, signaled by a flashing VERB 05 NOUN 09. This alarm indicates that the wrong thrusting program has been chosen for the vehicle configuration; i.e., the DPS has been staged for P40 or has not been staged for P42. The crew should key VERB 34 ENTR to terminate P40.

6.3.1.4 Restarts

Should a hardware restart occur, the RESTART light on the DSKY would be illuminated. A hardware or software restart will terminate automatic attitude maneuvers (R60). The crew can recover by keying PRO in response to the flashing VERB 50 NOUN 18 that returns to the DSKY after the restart.

BLANK

6.3.2 P41, Reaction Control System Maneuver—LGC

P41, one of the powered flight guidance programs, can be used to coordinate the timing of short, manually controlled Reaction Control System (RCS) burns whenever a change-of-orbit maneuver is required. During these burns, P41 maintains the LM state vector and provides the crew with a monitor of the maneuver's progress. A prethrust program, P3x, establishes the parameters needed for thrust control.

P41 uses the AVERAGEG routine for state-vector updating and the $\underline{v}_G$ updating cycles to compute DSKY displays. (Refer to subsection 6.1.)

6.3.2.1 P41 Procedures

Tables 6.3.2-I and -II show P41 displays and extended verbs, respectively. Figure 6.3.2-1 is a flowchart of P41.

Before entering P41, the following must be performed:

a. LGC turned on
b. R03, Autopilot Data Load routine
c. P3x, a prethrust program
d. ISS on for at least 15 minutes
e. IMU at a known orientation.

When the crew selects P41, the program performs the IMU Status Check Routine (R02) and illuminates the PROG light if the IMU is not operating (alarm code 00210) or if the IMU orientation is not known (alarm code 00220). At the completion of R02, the program computes the initial thrust direction of $\underline{v}_G$ and the preferred IMU orientation and then enters the Attitude Maneuver Routine (R60). R60 is similar to the CSM R60 except that the PGNS MODE CONTROL switch (on the STAB/CONT panel) is in the AUTO position for an automatic maneuver, and the flashing NOUN 18 display shows FDAI angles rather than gimbal angles. There is a possibility of a 00401 alarm, indicating that the final gimbal angles would produce gimbal lock. A 01301 alarm indicates an arc-sine or arc-cosine argument that is too large.

Upon completion (or termination) of R60, the DSKY displays (and updates every 1 second), VERB 16 NOUN 85; the three registers contain the three components of $\underline{v}_G$ in LM body axes.

TABLE 6.3.2-I

DISPLAYS ASSOCIATED WITH P41 (LM)

DSKY	Initiated by	Purpose	Description	Registers
V05 N09 E	Astronaut	Verify PROG alarm	Alarm Code / Condition 00210 IMU not on 00220 IMU orientation unknown 00401 Desired gimbal angles yield gimbal lock 01301 Arc-sine or arc-cosine argument too large 01703 t_{IG} slipped	R1 xxxxx * R2 xxxxx R3 xxxxx
FL V50 N18	R60	Display FDAI angles	FDAIX - roll FDAIY - pitch FDAIZ - yaw	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
V16 N85	P41	Display $\underline{v}_G$	Components of $\underline{v}_G$ in LM body axes	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V16 N85	P41	Signals t_{IG}	---	---
V06 N86E	Astronaut	On call display of $\underline{v}_G$	$\underline{v}_G$ components in local vertical coordinates	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
V16 N40E	Astronaut	Additional parameter display	TFI—time from t_{IG} VG—magnitude of $\underline{v}_G$ ΔVM—measured Δv magnitude	R1 xxBxx min, sec R2 xxxx.x fps R3 xxxx.x ft/sec

* The alarm codes are displayed as follows:
R1 = First alarm following error reset
R2 = Second alarm following error reset
R3 = Most recent alarm

TABLE 6.3.2-II

EXTENDED VERBS FOR USE WITH P41 (LM)

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters (apogee, perigee, time of free fall)	FL V16 N44 R1 = xxxx. x n. mi. R2 = xxxx. x n. mi. R3 = xxBxx min, sec
83 ENTR	Do R31	Display rendezvous parameters (range; range rate; theta, the angle between local horizontal and the LM+Z-axis)	FL V16 N54 R1 = xxx. xx n. mi. R2 = xxxx. x ft/sec R3 = xxx. xx deg

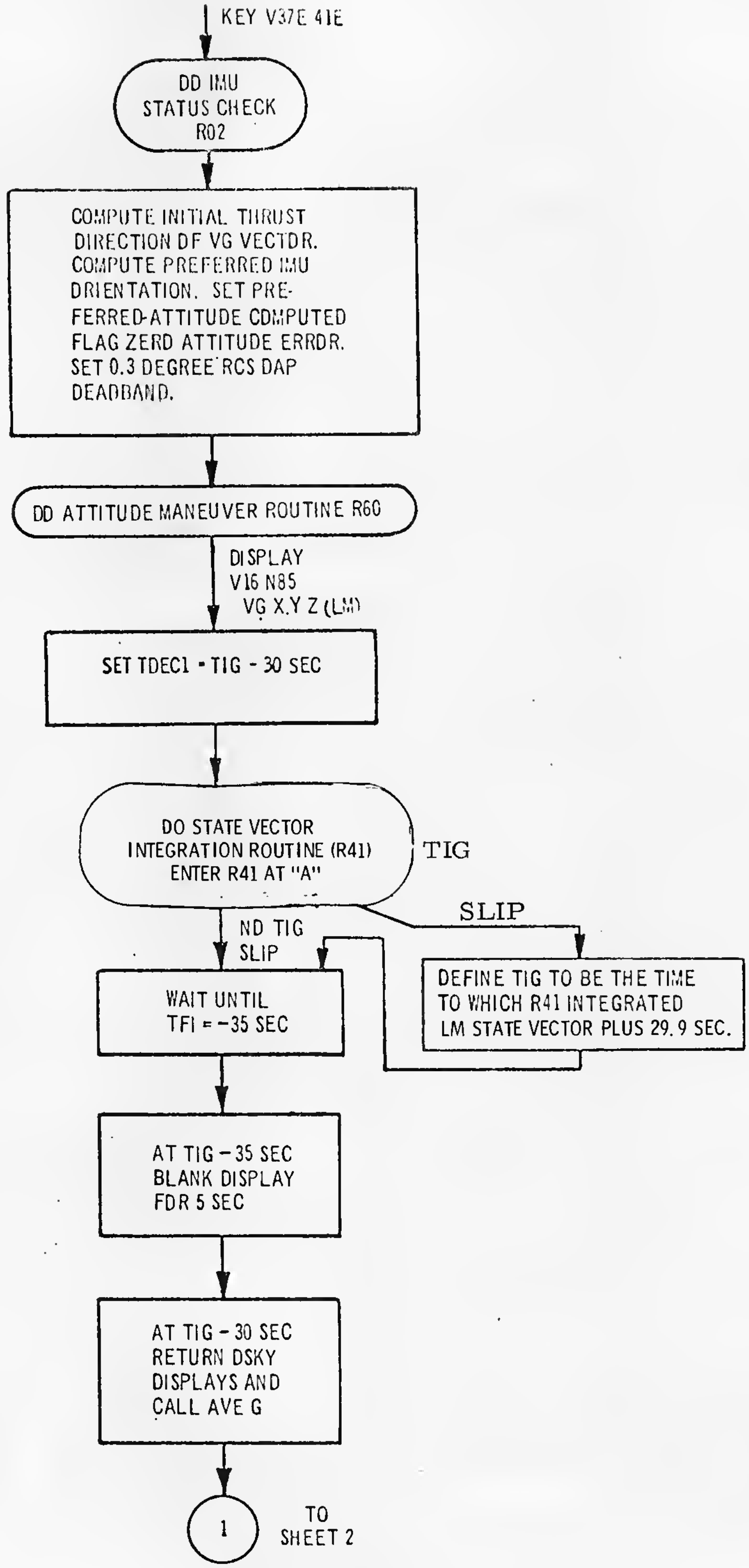

Figure 6.3.2-1. Reaction Control System Maneuver Program (LM P41)
(Sheet 1 of 2)

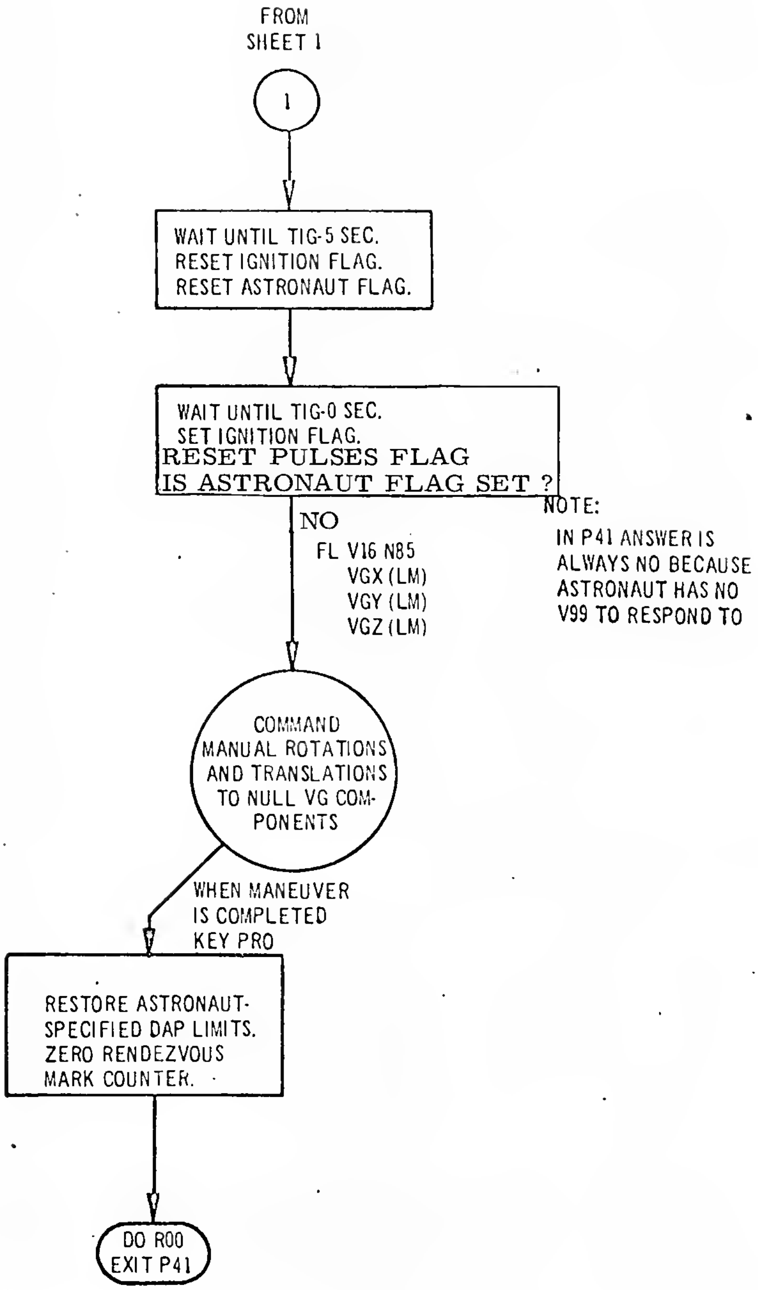

Figure 6.3.2-1. Reaction Control System Maneuver Program (LM P41)
(Sheet 2 of 2)

The program next enters the State Vector Integration Routine, which integrates the LM state vector ahead to t_{IG} -30 seconds. (Refer to paragraph 6.3.1.2.2.) Other than the COMP ACTY light, the only visible sign that the routine is being performed would be the possible occurrence of alarm 01703 indicating t_{IG} has been slipped to allow sufficient time to complete integration. The new t_{IG} will be used for the time-of-ignition displayed in R1 of VERB 06 NOUN 40 after integration has been completed.

At t_{IG} -35 seconds, the DSKY will be blanked for 5 seconds, after which the DSKY displays return, indicating the start of AVERAGEG and the $\underline{v}_G$ updating cycles.

At t_{IG}, the DSKY will flash VERB 16 NOUN 85 to request response. The crew should null the residual $\underline{v}_G$ by using the manual controls. Upon completion of thrusting, the crew keys PRO to end major mode P41.

The crew can select the Orbital-parameters Display (VERB 82 ENTR) to check for reasonable pericenter. The crew keys PRO to return to the flashing VERB 37 display.

AVERAGEG continues running until a new major mode is selected. Therefore, immediate new-mode selection is imperative to avoid accumulation of PIPA bias errors.

6.3.2.2 Alarms

The alarm codes that may occur in P41 are listed below; a detailed explanation of each is given in paragraph 6.3.1.3:

a. Alarm code 00210 occurs if the IMU is not on.
b. Alarm code 00220 occurs if the IMU orientation is unknown.
c. Alarm code 00401 occurs if the desired gimbal angles would yield gimbal lock.
d. Alarm code 01301 occurs if an arc-sine or arc-cosine argument is too large.
e. Alarm code 01703 occurs if the time-of-ignition is slipped.

6.3.2.3 Restarts

Should a hardware restart occur during P41, the RESTART light on the DSKY would be illuminated. A hardware or software restart will terminate automatic attitude maneuvers (R60). The crew can recover by keying PRO in response to the flashing VERB 50 NOUN 18 that returns to the DSKY after the restart.

6.3.3 P42, Ascent Propulsion System Maneuver—LGC

The powered flight guidance program, P42, coordinates the timing of some Ascent Propulsion System (APS) maneuvers; maintains the LM state vector; guides and controls the thrust direction—so as to achieve the desired velocity at the end of the maneuver; and provides the crew with a monitor of the maneuver's progress.* The LM P42 behaves much as the LM P40. (Refer to paragraph 6.3.1.)

The ascent engine is neither throttleable nor gimbaled. The PGNCS automatically issues on and off commands to the ascent engine. These commands can be overridden by the crew.

There are several limitations to the use of the ascent engine of which the following is a partial list.**

a. The ascent engine must not be started more than 35 times.

b. The APS must not remain pressurized longer than 24 hours. If this limit is exceeded, the pressure regulator assemblies may not operate.

c. The ascent engine combustion chamber must not be subjected to more than 460 seconds of engine operation. Exceeding this limit will cause the engine to operate with a severely charred combustion chamber, resulting in burn-through.

A targeting program, P3x, will establish the parameters needed for thrust control guidance. After the appropriate P3x has been performed, the astronaut must not select another P3x, a P7x, or P47 before the burn. These programs use some of the same variable computer storage locations and would destroy the thrusting parameters established by the original P3x for this burn.

P42 uses the AVERAGEG routine for state vector updating and cross-product steering for guiding the thrust direction. AVERAGEG and cross-product steering are discussed in subsection 6.1.

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*The APS Maneuver Program is not used during powered ascent, or during P71, the APS Abort Program.

**A more complete list can be found in the APOLLO Operations Handbook, Lunar Module, Volume I, Document No. LMA790-3-LM5.

6.3.3.1 P42 Procedures

Tables 6.3.3-I and -II show P42 displays and extended verbs, respectively. Figure 6.3.3-1 is the program flowchart. Before entering P42, the following must be performed:

a. LGC turned on
b. R03, Autopilot Data Load Routine
c. P3x, a prethrust program
d. ISS on for at least 15 minutes
e. IMU at a known orientation.

Crew procedures specify how long before APS ignition the crew must select P42 to allow sufficient time for performing the necessary routines. The program first checks for the presence of the DPS. If the DPS has not been staged, the DSKY flashes VERB 05 NOUN 09 and display alarm code 01706. The crew has two choices: either terminate P42 by keying VERB 34 ENTR, or key PRO and stage the DPS in the time interval between t_{IG} -30 seconds and t_{IG}. The DPS is staged by depressing either the STAGE or the ABORT STAGE pushbuttons.

The program next enters the IMU Status Check Routine (R02) as in the CSM P40. Upon completion of R02, the program computes the initial thrust direction of $\underline{v}_G$ and the preferred IMU orientation and then enters the Attitude Maneuver Routine (R60). This routine is similar to the CSM R60 except that the PGNS MODE CONTROL switch (on the STAB/CONT panel) is in the AUTO position for an automatic maneuver, the NOUN 18 display shows FDAI angles rather than gimbal angles, and there is no nonflashing VERB 06 NOUN 18 display during the maneuver. There is a possibility of a 00401 alarm, indicating that the final or initial gimbal angles would yield gimbal lock. A 01301 alarm would indicate an arc-sine or arc-cosine argument is too large.

Upon completion (or termination) of R60, the program checks whether the GUID CONT switch has been set to PGNS, the PGNS MODE CONTROL switch to AUTO, and the THR CONT to AUTO (if the DPS has not been staged). If these settings have not been selected, the DSKY flashes VERB 50 NOUN 25 with R1 containing 00203. (Refer to paragraph 6.3.1.1 for procedures to follow if proper switch settings have been made and flashing VERB 50 NOUN 25 still occurs.) To make the selections, the crew places the GUID CONT switch in the PGNS position and the PGNS MODE CONTROL switch in the AUTO position (the THR CONT in AUTO if the DPS has not been staged) and keys PRO. Otherwise, the crew keys ENTR.

TABLE 6.3.3-I

DISPLAYS ASSOCIATED WITH P42 (LM) (SHEET 1 OF 2)

DSKY	Initiated by	Purpose	Condition		Registers
			Alarm Code	Condition	
V05 N09E	Astronaut	Verify PROG alarm	00210 00220 00401 01301 01407 01703	IMU not on IMU orientation unknown Desired gimbal angles yield gimbal lock Arc sine or arc cosine argument too large $\underline{v}_G$ increasing t_{IG} slipped	R1 xxxxx* R2 xxxxx R3 xxxxx
FL V05 N09	P42	Display alarm	01706	DPS not staged	R1 xxxxx* R2 xxxxx R3 xxxxx
FL V50 N18	R60	Display FDAI angles to request maneuver	FDAIX - FDAIY - FDAIZ -	roll pitch yaw	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg
FL V50 N25	P42	Switch to PGNCS automatic mode. If PGNCS automatic mode desired, make the following switch selections. Refer also to paragraph 6.3.1-1: GUID CONT → PGNS PGNS MODE CONT → AUTO THR CONT → AUTO (if the DPS has not been staged)	00203—checklist code		R1 00203 R2 Blank R3 Blank

* The alarm codes are displayed as follows:
R1 = First alarm following error reset
R2 = Second alarm following error reset
R3 = Most recent alarm

TABLE 6.3.3-I

DISPLAYS ASSOCIATED WITH P42 (LM) (SHEET 2 OF 2)

DSKY	Initiated by	Purpose	Condition	Registers
V06 N40	P42	Display	Time from t_{IG} v_G magnitude Sum of acquired velocity	R1 xxBxx min, sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V99 N40	P42	Request APS engine-on enable	---	---
FL V97 N40	R40	Low thrust detected	---	---
FL V16 N40	P42	Display final values	Time from cutoff at last cycle Remaining v_G magnitude Sum of acquired velocity	R1 xxBxx min, sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
FL V16 N85	P42	Display remaining $\underline{v}_G$	Components of $\underline{v}_G$ in LM body axes	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec
V06 N86E	Astronaut	On call display of $\underline{v}_G$	$\underline{v}_G$ components in local vertical	R1 xxxx.x ft/sec R2 xxxx.x ft/sec R3 xxxx.x ft/sec

TABLE 6.3.3-II

EXTENDED VERBS FOR USE WITH P42 (LM)

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters (apogee, perigee, time of free fall)	FL V16 N44 R1 = xxxx.x n.mi. R2 = xxxx.x n.mi. R3 = xxBxx min, sec
83 ENTR	Do R31	Display rendezvous parameters (range; range rate; and theta, the angle between local horizontal and LM + Z-axis)	FL V16 N54 R1 = xxx.xx n.mi. R2 = xxxx.x ft/sec R3 = xxx.xx deg

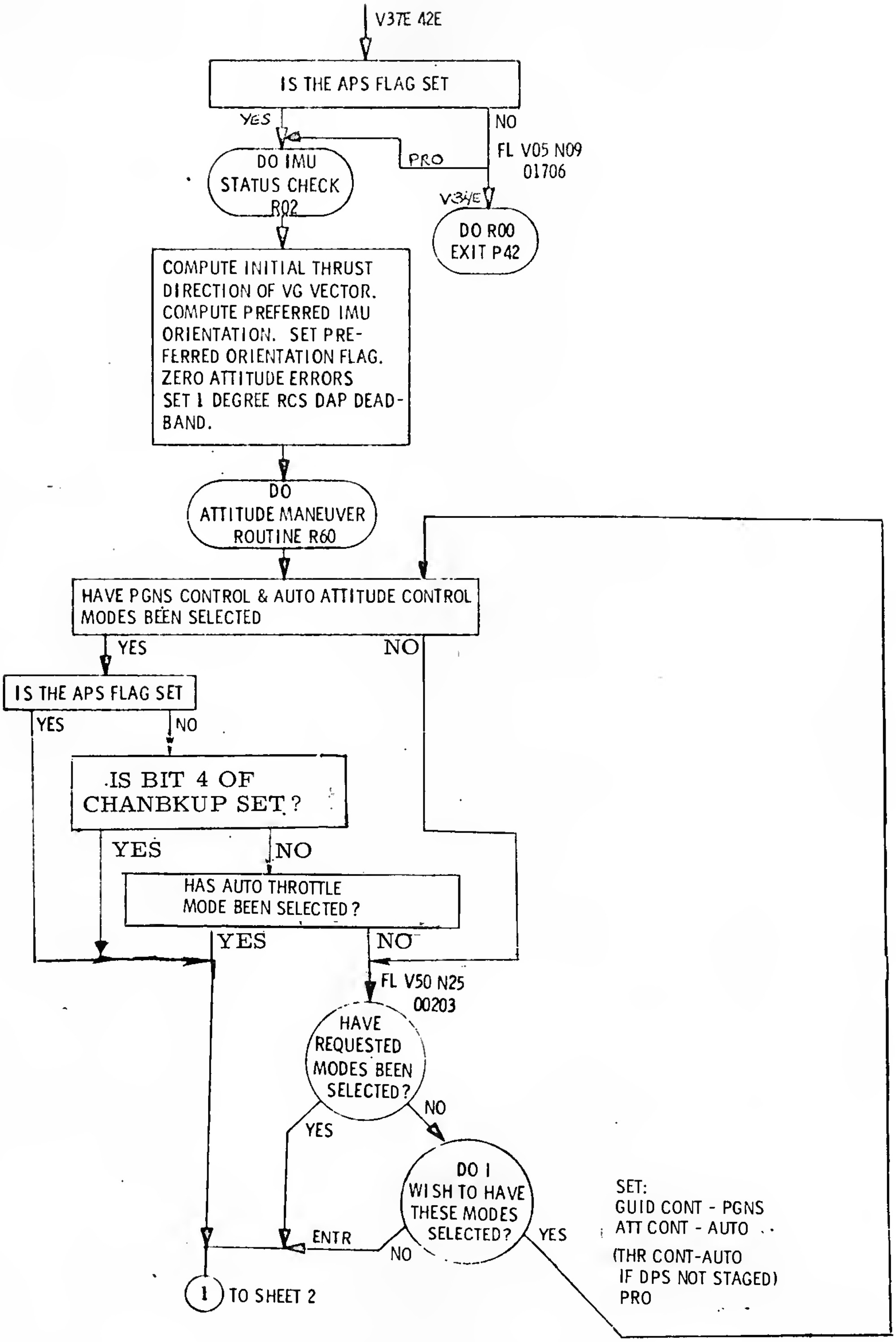

Figure 6.3.3-1. APS Maneuver Program (LM P42) (Sheet 1 of 3)

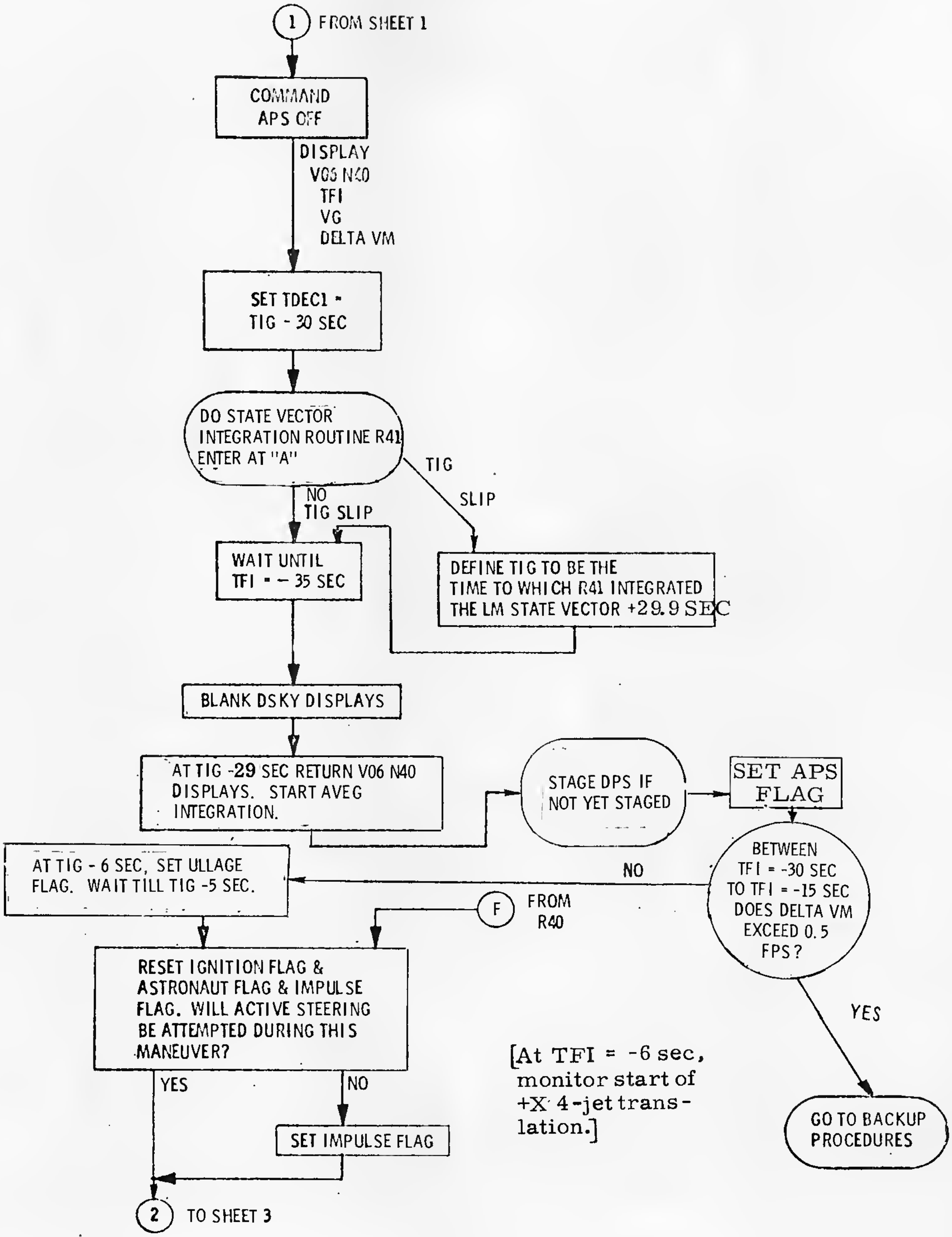

Figure 6.3.3-1. APS Maneuver Program (LM P42) (Sheet 2 of 3)

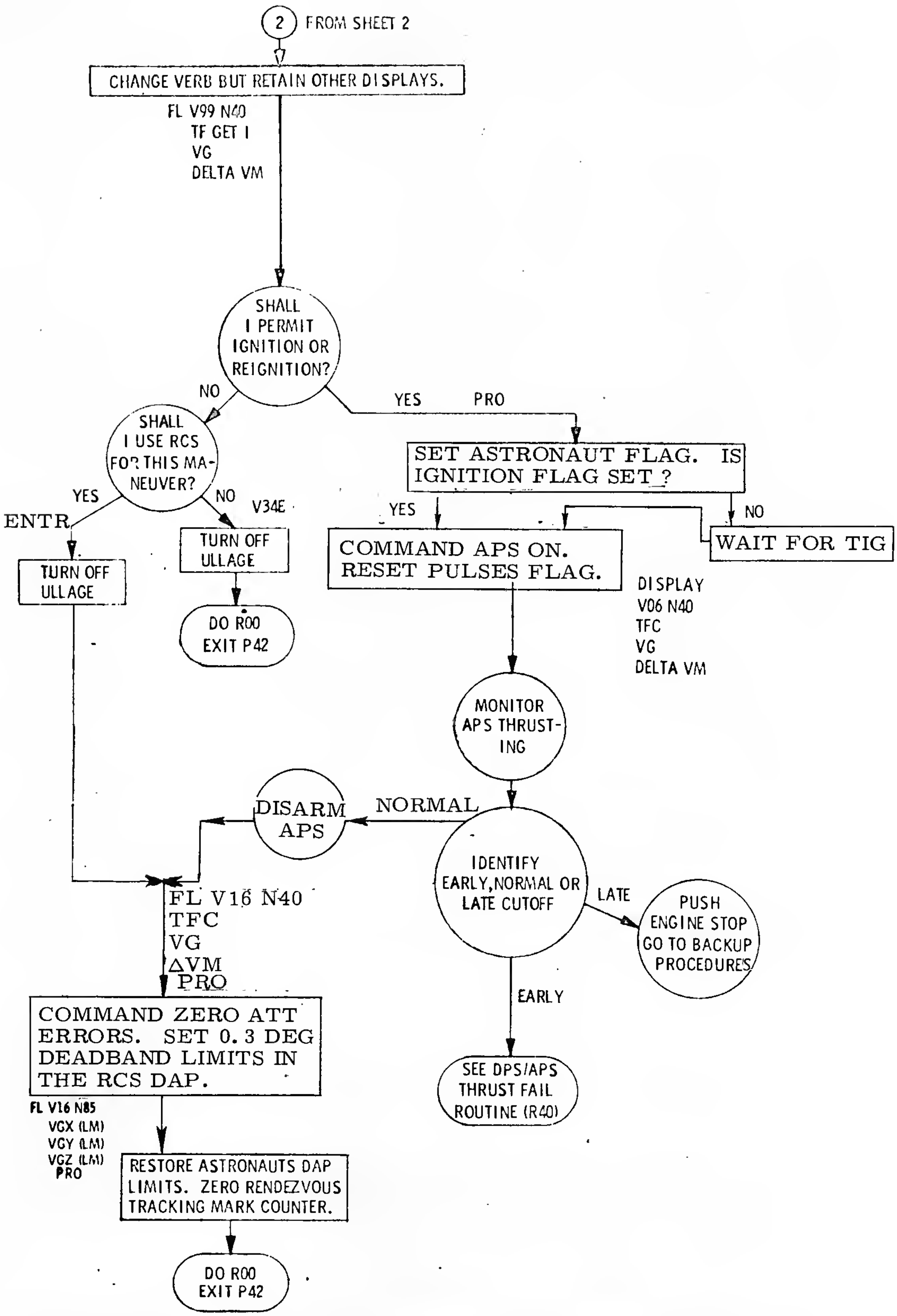

Figure 6.3.3-1. APS Maneuver Program (LM P42) (Sheet 3 of 3)

Next the program commands the APS off and displays VERB 06 NOUN 40, with the registers containing the following:

R1 = time from t_{IG}
R2 = magnitude of velocity-to-be-gained
R3 = magnitude of Δv

The program next enters the State Vector Integration Routine (refer to paragraph 6.3.1.2.2), which integrates the LM state vector ahead to t_{IG} -30 seconds. During R41, the COMP ACTY light illuminates; the other visible sign that R41 is running is the possible occurrence of an alarm (alarm code 01703), indicating t_{IG} has been slipped to allow sufficient time to complete integration. The new t_{IG} will be used for the time-from-ignition displayed in R1 of VERB 06 NOUN 40 after integration has been completed.

At t_{IG} -35 seconds, the DSKY will be blank for 5 seconds. At t_{IG} -29 (R1 = -00B29), the VERB 06 NOUN 40 display will return, indicating the start of AVERAGEG and cross-product steering cycles. For the next 15 seconds, the crew should watch R3 to see that it does not exceed 0.5 ft/sec, which would indicate excessive PIPA bias errors. If excessive PIPA bias errors are so detected, the crew should go to backup procedures.

If the DPS has not been staged, the crew must stage it between t_{IG} -30 seconds and t_{IG}. At t_{IG} -6.0 seconds, ullage begins. At t_{IG} -5.0 seconds, the program flashes VERB 99 NOUN 40 to request "please perform engine-on enable." After sufficient ullage, as indicated by an increase in R3, the crew permits APS ignition by keying PRO. To avoid the burn altogether—and not permit ignition—the crew can key VERB 34 ENTR. To complete the maneuver with the RCS jets, the crew can key ENTR.

If the astronaut has chosen to permit ignition, the VERB 06 NOUN 40 display returns until t_{IG}. After ignition, R1 will contain time from cutoff (TFC), which is initially calculated and displayed. This display will count down with elapsed time until TVC steering is initiated, when TFC is recalculated every 2 seconds by the guidance equations. The display of TFC is updated every 1 second. If the burn is to be impulsive (i.e., TFC < 6 sec), it will be done with no steering.

The crew can identify early, normal, or late engine cutoff from assessment of DSKY displays. If engine cutoff is late, the crew can depress the engine STOP pushbutton and go to backup procedures. An early cutoff would be detected by the program,

which would then transfer control to R40, the Thrust Fail Routine (paragraph 6.3.1.2.1). After normal cutoff, the crew disarms the APS.

The DSKY flashes VERB 16 NOUN 40 to request proceed. The crew can record the register values, as desired, and key PRO.

The DSKY flashes VERB 16 NOUN 85, to request response, and displays the components of the current velocity-to-be-gained resolved along the LM axes. The $\underline{v}_G$ vector will be updated by the cross-product steering computations, every 2-second cycle. The crew also has the choice of nulling the $\underline{v}_G$ components using manual controls. At this point, the Orbital-parameters Display Routine (R30) can be selected (VERB 82 ENTR) to check for reasonable pericenter. To exit P42, the crew keys PRO in response to the flashing VERB 16 NOUN 85.

AVERAGEG continues running until a new major mode is selected. Therefore, immediate new-mode selection is imperative to avoid accumulation of PIPA bias errors.

6.3.3.2 Alarms

A list of alarm codes that may occur in P42 follows; a detailed description is given in paragraph 6.3.1.3:

a. Alarm code 00210 occurs if the IMU is not operating.
b. Alarm code 00220 occurs if the IMU orientation is unknown.
c. Alarm code 00401 occurs if the desired gimbal angles would yield gimbal lock.
d. Alarm code 01301 occurs if an arc-sine or arc-cosine argument is too large.
e. Alarm code 01407 occurs if the velocity-to-be-gained is increasing.
f. Alarm code 01703 occurs if t_{IG} is slipped.
g. Alarm code 01706 occurs if P42 is selected but the DPS has not been staged. The crew may choose to continue P42, staging the DPS between t_{IG} - 30 seconds and t_{IG}, by responding to the flashing display with PRO.

6.3.3.3 Restarts

Should a hardware restart occur, the RESTART light on the DSKY would be illuminated. A software or hardware restart will terminate automatic attitude maneuvers (R60). The crew can recover by keying PRO in response to the flashing VERB 50 NOUN 18 that returns to the DSKY after the restart.

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6.3.4 P47, Thrust Monitor—LGC

P47, the powered flight monitor program, maintains the LM state vector during a thrusting maneuver not controlled by the GNCS and provides a monitor of the maneuver's progress for the crew. The program uses the AVERAGEG routine for state vector updating. (For an explanation of AVERAGEG use, refer to subsection 6.1.) There is no important difference between the thrust monitor programs for the CSM and the LM.

6.3.4.1 P47 Procedures

Tables 6.3.4-I and -II present the displays and extended verbs associated with P47. Figure 6.3.4-1 is the program flowchart. Before entering P47, the LGC and the ISS must be on—the latter for at least 15 minutes.

Upon selection of P47, shortly before t_{IG}, the program performs the IMU Status Check Routine (R02) and illuminates the PROG light if the ISS is off (i.e., alarm code 00210) or the IMU orientation is unknown (alarm code 00220).

At the completion of R02, the program enters the State Vector Integration Routine (R41), which integrates the LM state vector ahead to 20 seconds from the start of the last time step. The AVERAGEG cycle begins at that time. (Refer to paragraph 6.3.1.2.2 for a description of R41.)

The DSKY displays a flashing VERB 16 NOUN 83 with the three components of acquired $\Delta \underline{v}$, in control coordinates. The registers contain zeros initially; the contents are updated every 2 seconds.

While the thrusting maneuver is performed, the crew must monitor the FDAI ball to avoid gimbal lock. At the end of the maneuver, the crew can recycle the display (zeroing the registers), by keying in VERB 32 ENTR.

To terminate major mode P47, the crew keys PRO. The DSKY then flashes VERB 37, requesting the selection of a new major mode. It is important to respond to this immediately to terminate AVERAGEG and thus to avoid accumulation of PIPA bias errors.

6.3.4.2 Alarms

The PROG alarm codes associated with P47 are listed below. A detailed description of each is given in paragraph 6.3.1.3.

TABLE 6.3.4-I

DISPLAYS ASSOCIATED WITH P47 (LM)

DSKY	Initiated by	Purpose	Condition	Register
V05 N09E	Astronaut	Verify PROG alarm	00210 ISS not on 00220 IMU orientation unknown	R1 xxxxx * R2 xxxxx R3 xxxxx
FL V16 N83	P47	Display $\Delta \underline{v}$ acquired	Three components in control coordinates	R1 xxxx. x ft/sec R2 xxxx. x ft/sec R3 xxxx. x ft/sec

* The alarm codes are displayed as follows:
R1 = First alarm following error reset
R2 = Second alarm following error reset
R3 = Most recent alarm

TABLE 6.3.4-II

EXTENDED VERBS FOR USE WITH P47 (LM)

VERB	Identification	Purpose	Remarks
82 ENTR	Do R30	Compute and display relevant orbital parameters (apogee; perigee; and time of free fall)	FL V16 N44 R1 = xxxx. x n. mi. R2 = xxxx. x n. mi. R3 = xxBxx min, sec
83 ENTR	Do R31	Display rendezvous parameters (range, range rate and theta, the angle between local horizontal and the LM +Z-axis)	FL V16 N54 R1 = xxx. xx n. mi. R2 = xxxx. x ft/sec R3 = xxx. xx deg

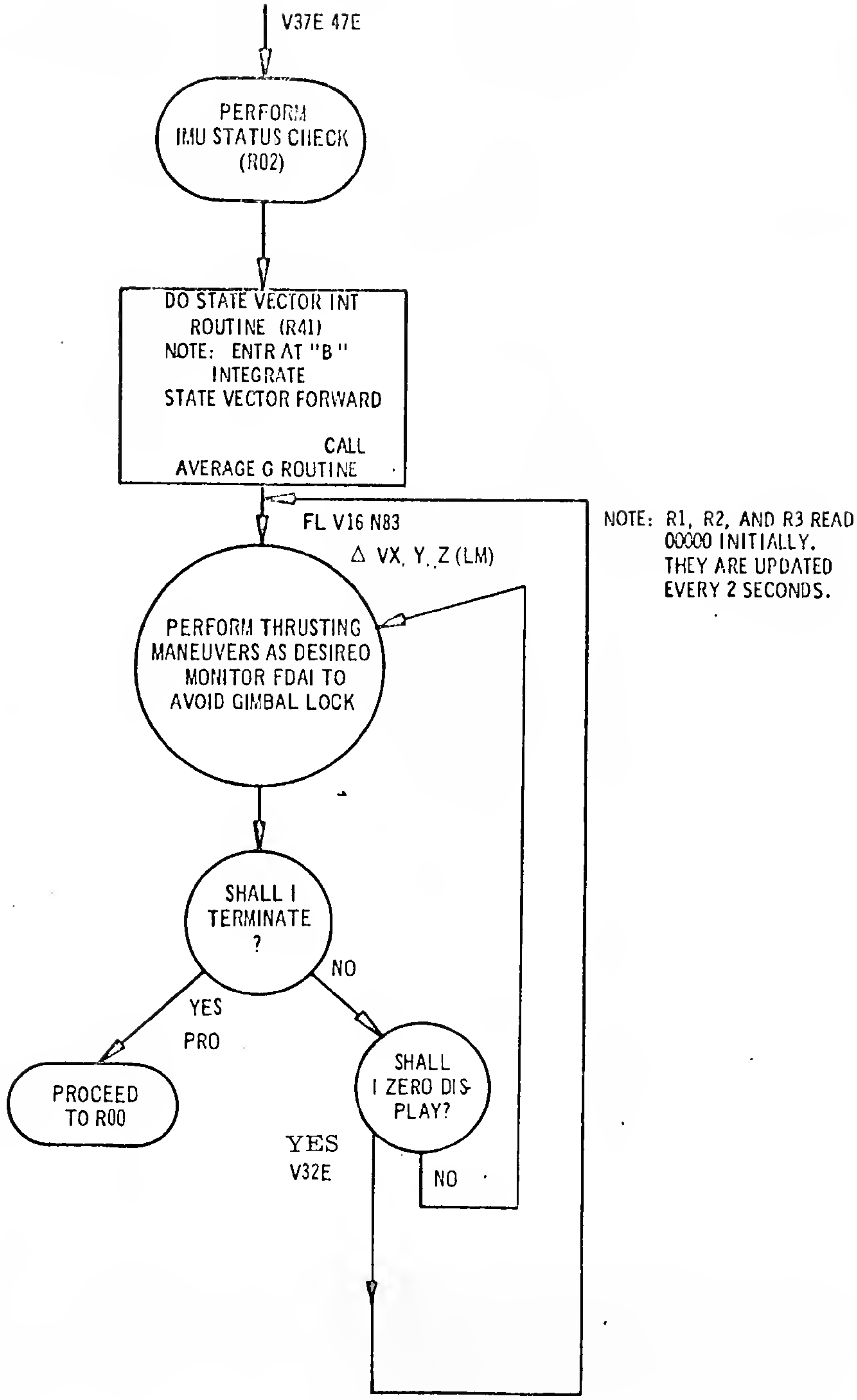

Figure 6. 3. 4-1. Thrust Monitor Program (LM P47)

a. Alarm code 00210 occurs if the ISS is not on.

b. Alarm code 00220 occurs if the IMU orientation is not known.

6.3.4.3 Restarts

Should a hardware restart occur, the RESTART light on the DSKY would be illuminated; no other effects would be noticed by the crew.

SECTION 7.0

ALIGNMENT

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7.1 INTRODUCTION TO APOLLO GUIDANCE COMPUTER (AGC) ALIGNMENT PROGRAMS

The following alignment programs enable the APOLLO flight crew to establish and maintain the spacecraft's inertial attitude reference:

CSM:	P51 — IMU Orientation Determination Program
	P52 — IMU Realignment Program
	P53 — Backup IMU Orientation Determination Program
	P54 — Backup IMU Realignment Program
LM:	P51 — Inflight IMU Orientation Determination Program
	P52 — Inflight IMU Realignment Program
	P57 — Lunar Surface Alignment Program.

Section 7.0 is organized as follows: subsection 7.1 reviews the major components of the GNCS (and LM PGNCS) and then describes the role of the alignment programs, their coordinate systems, and the general techniques of orienting and realigning the Inertial Measurment Unit (IMU); subsection 7.2 describes in detail the operation of the CSM alignment programs; subsection 7.3 describes the LM alignment programs.

7.1.1 GNCS Operation

Table 7.1-I lists the principal GNCS components and their functions; Figures 7.1-1 and -2 show the inertial subsystem (ISS) interfaces for the CSM and LM, respectively. The stabilization loop shown in the figures holds the stable member in a constant orientation relative to inertial space (i.e., in a constant orientation relative to the stars) by isolating the stable member from roll, pitch, and yaw motions of the spacecraft. The stabilization loop operates as follows: (1) the inertial reference integrating gyros (IRIGs) mounted on the stable member generate error signals to indicate any change in the inertial orientation of the stable member; (2) the error signals are amplified by servo amplifiers in the power and servo assembly (PSA) and fed to gimbal torque motors, which rotate the stable member about the outer-, middle-, and inner-gimbal axes (Figure 7.1-3); (3) the amount and direction of stable-member rotation are such as to reduce the IRIG error signal to zero, returning the stable member to its original orientation. In this condition, the ISS is said to be in the <u>inertial-reference mode</u>.

TABLE 7.1-I

APOLLO GUIDANCE, NAVIGATION AND CONTROL SYSTEM PRINCIPAL COMPONENTS (SHEET 1 OF 2)

COMPONENT	VEHICLE	FUNCTION
Navigation Base (NB)	CM and LM	Attachment fixture to hold IMU and OUA (CM) or AOT (LM) in precise alignment to spacecraft structure.
Inertial Measurement Unit (IMU)	CM and LM	Maintain an inertial reference from which to measure vehicle attitude changes and accelerations.
Optical Unit Assembly (OUA)	CM only	Contains a sextant (SXT) and Scanning Telescope (SCT) used to determine optical lines-of-sight to celestial bodies and to the LM.
Alignment Optical Telescope (AOT)	LM only	Optical telescope used to determine lines-of-sight to celestial bodies.
Power and Servo Assembly (PSA)	CM and LM	Provide central mounting point for GNCS and PGNCS power supplies, amplifiers, and other modular electronic components.
Pulse Torque Assembly (PTA)	LM only	Supplies and processes inputs and outputs to the IMU inertial components.
Signal Conditioner Assembly (SCA)	CM and LM	Receives signals from GNCS or PGNCS and converts them to a form acceptable for telemetry equipment inputs.
Command Module Computer (CMC) and LM Guidance Computer (LGC)	CM and LM, respectively	Performs flight, rendezvous, tracking, and (LM) landing data management and calculations.
Coupling Data Unit (CDU)	CM and LM	Analog to digital conversion of IMU gimbal angles and (CM) optics shaft and trunnion angles or (LM) rendezvous radar shaft and trunnion angles; digital to analog conversion of computer derived data; control of inertial subsystem modes of operation using computer issued discretes; failure detection.

TABLE 7.1-I

APOLLO GUIDANCE, NAVIGATION AND CONTROL SYSTEM PRINCIPAL COMPONENTS (SHEET 2 OF 2)

COMPONENT	VEHICLE	FUNCTION
Display Keyboard (DSKY)	CM(2) and LM (1)	Input-output device between astronaut and AGC
Guidance and Navigation Indicator Control Panel (GNICP)	CM only	Mounting panel for GNCS controls and indicators.

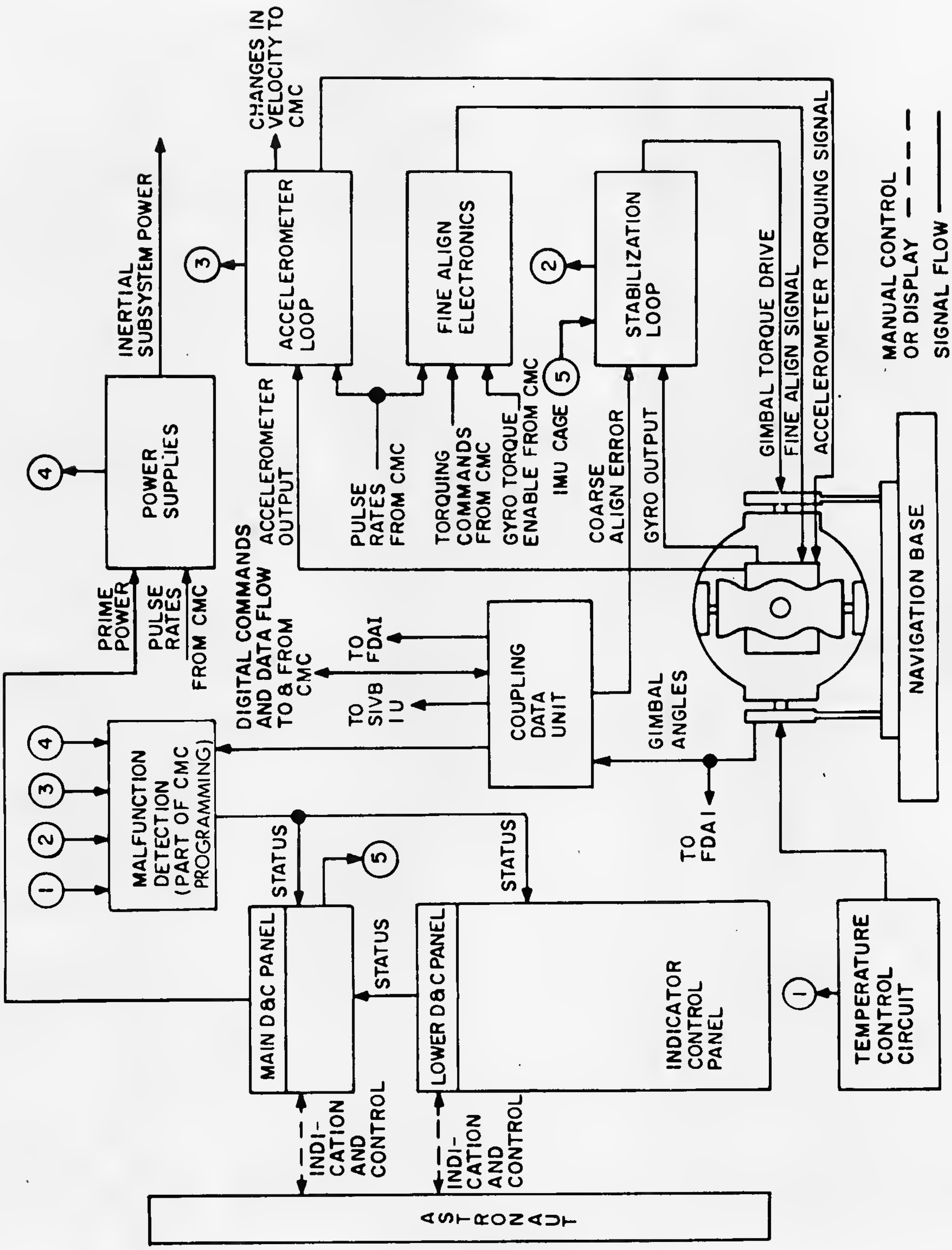

Figure 7.1-1. CSM Inertial Subsystem Interface

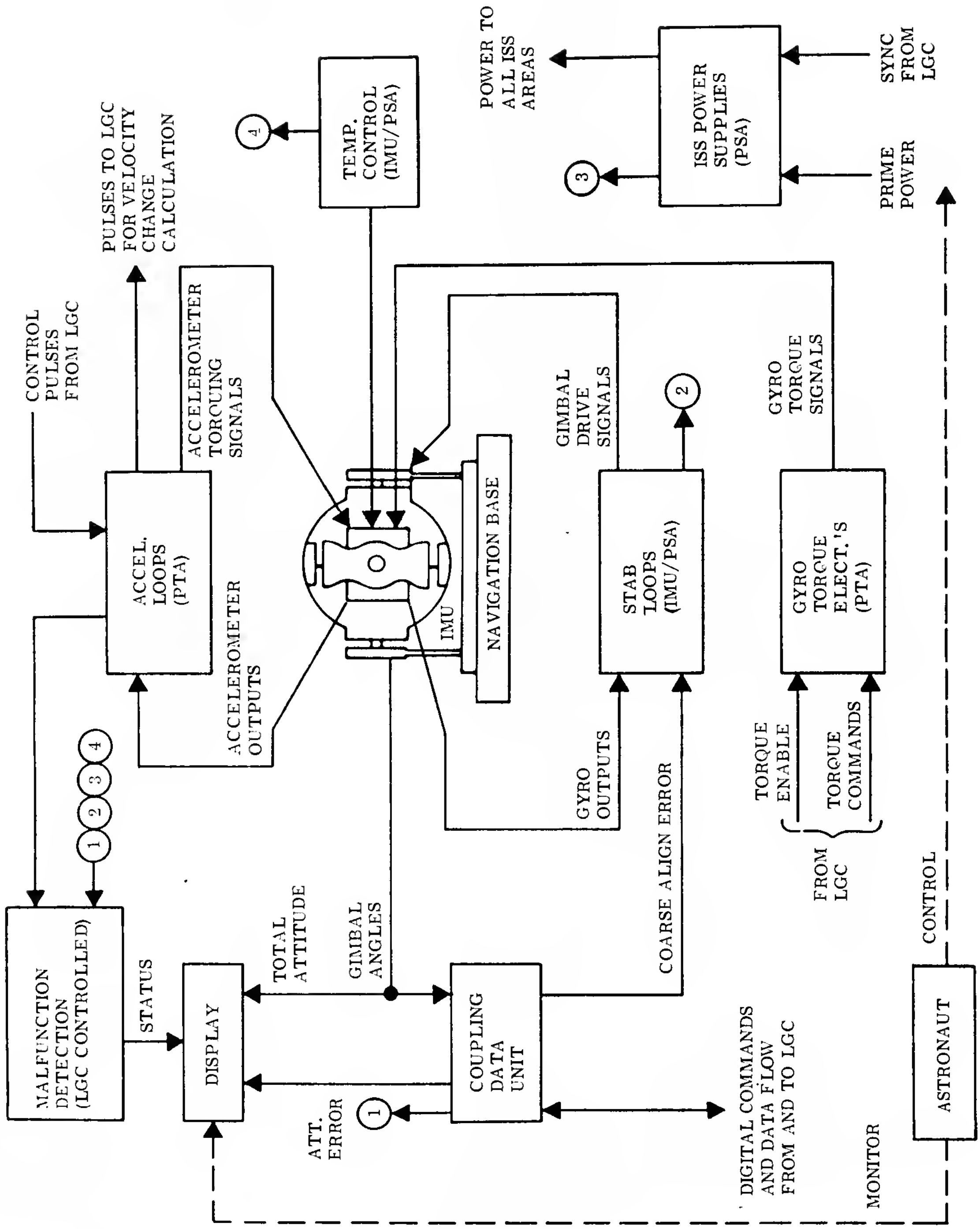

Figure 7.1-2. LM Inertial Subsystem Interface

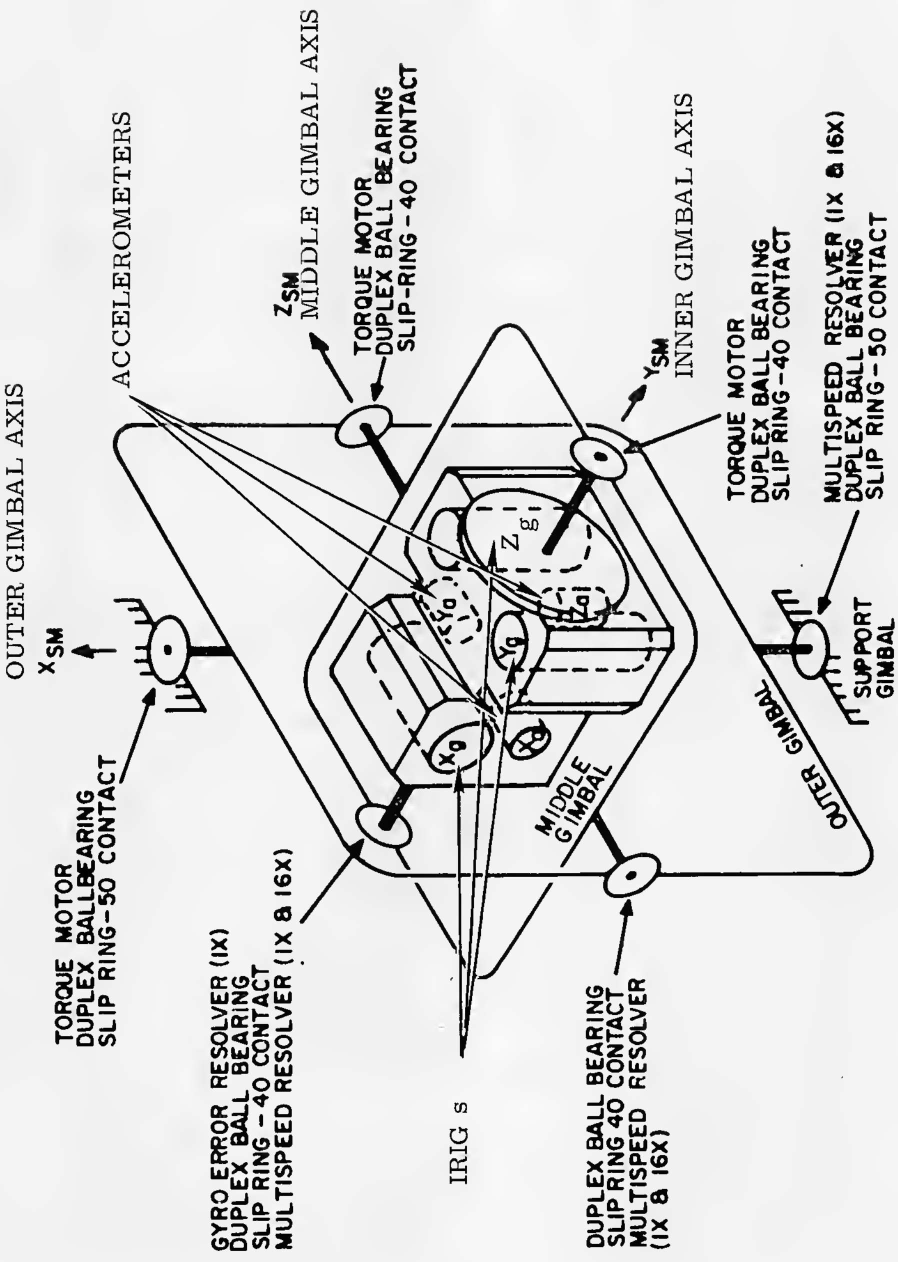

Figure 7.1-3. IMU Gimbal Assembly

The inertial orientation of the stable member can be changed by placing the ISS in either the coarse- or fine-alignment mode. The coarse-alignment mode allows the AGC to rapidly align the stable member to a desired position with a limited degree of accuracy. During coarse alignment, the astronaut or the computer can specify the desired gimbal angles to place the stable member in the required orientation. The computer then calculates the required gimbal angle changes and supplies to the coupling data unit (CDU) a train of pulses corresponding to the desired gimbal angle changes. The CDU supplies an analog error signal, equivalent to the AGC digital gimbal-angle information, to the PSA servo amplifiers. The amplifiers drive the gimbal torque motors to the desired angles. In the coarse-align mode, the error signals from the IRIGs are removed from the PSA servo amplifier inputs. This opens the stabilization loops, causing inertial reference to be lost. Additional stable member orientation errors will be present if the spacecraft is rotating during coarse alignment. As the gimbals are driven, the gimbal angles are read by resolvers mounted on the gimbal axes. If, after a maximum of 15 sec, the actual and desired gimbal angles differ by more than two degrees, the computer issues an alarm to the crew.

During P52 and P54, the astronaut has the option of selecting or bypassing the ISS coarse-align mode. This option is discussed in the paragraphs dealing with the individual programs. The astronaut can also command coarse-align mode independently of the P50s via DSKY entry of VERB 41 NOUN 20 (paragraphs 7.2.2.7 and 7.3.2.6).

Unless the Saturn DAP is operating with AVERAGEG, the coarse-align mode is also entered automatically whenever the middle gimbal angle exceeds 85 degrees (gimbal lock). During gimbal lock, the stable member will be held at a constant orientation relative to the spacecraft; the stable member's current inertial orientation will then be unknown.

The ISS fine-align mode is used to reposition the stable member with a greater degree of precision, but with less speed, than is available in the coarse-align mode. Coarse alignment to any set of gimbal angles takes about 15 sec; fine alignment requires about 2 sec per degree, one gimbal axis at a time. An advantage of the fine-align ISS mode, however, is that the stabilization loops remain closed, and the stable member provides an inertial attitude reference throughout the realignment process.

Fine alignment is accomplished by a process known as pulse torquing. The computer selects a particular IRIG and issues pulses to the fine-align electronics, located in

the CM PSA and the LM pulse torque assembly (PTA). The number of pulses corresponds to the required gimbal angle change about the desired IRIG axis. The fine-align electronics then send a precisely controlled dc current through a winding located in the selected IRIG. When current passes through the winding, a torque is induced in the gyro wheel, and the IRIG generates an error signal. The stabilization loop then drives the gimbals to reposition the stable member. By controlling the duration and polarity of torquing current sent to each IRIG, the stable member can be repositioned to any desired inertial orientation, to a precision of about 40 arc sec.

Before and after pulse torquing, the ISS is in the inertial-reference mode. In the fine-align mode, the torquing current in the IRIGs is precisely controlled and the stabilization loops remain closed; hence, the ISS remains sensitive to spacecraft attitude changes, even though the stable-member inertial orientation is slowly changing. The ISS thus retains its attitude reference capabilities before, during, and after pulse torquing.

During P52 and P54, the astronaut has the option of selecting or bypassing the ISS fine-align mode. This option, and the coarse-align option, are discussed in detail in the paragraphs dealing with the P50s individually. The astronaut can also, independently of the P50s, initiate the fine-align mode and specify the gyro torquing angles via VERB 42 (paragraphs 7.2.2.7 and 7.3.2.6).

7.1.2 Coordinate Systems

The stable member's inertial attitude must be stored in the computer for it to serve as a reference for propulsion-system burns, navigation, maneuvers, and crew displays. Several coordinate systems are used; they all consist of three mutually perpendicular axes arranged in the conventional right-hand triad, with the exception of the SXT and AOT coordinate systems (items g and h below). The coordinate systems are defined here:

a. Basic-Reference Coordinate System.—This is an inertial, non-rotating coordinate system, oriented in a fixed direction with respect to the stars. The origin is located at either the earth's or moon's center of mass; the orientation is defined by the line of intersection of the mean earth equatorial plane and the plane defined by the mean orbit of the earth on approximately January 1. The x-axis is along this line of intersection, which is nearly parallel to the minor axis of the earth's orbit about the sun; the z-axis is along the mean earth north pole; and the y-axis

completes the right-hand triad. In the CMC, the origin of this system is shifted from the earth's mass center to the moon's mass center when the vehicle first falls within the moon's sphere of influence (about 40,000 statute miles from the moon's center), and is shifted back to earth when the vehicle leaves the moon's sphere of influence. The vectors stored in the computer to describe the navigation stars, earth, moon, and sun positions, as well as spacecraft position and velocity, refer to the Basic-Reference Coordinate System.

b. Vehicle, or Body, Coordinate System.—This coordinate system represents the spacecraft's structure. In the CM, the x-axis lies along the vehicle's longitudinal axis, positive in the nominal SPS thrust direction. The positive z-axis is defined by an alignment target located at the top of the service module (below the astronaut's feet when in the couch) and is normal to the x-axis. The y-axis is defined to complete the right-hand triad.

In the LM, the x-axis lies along the longitudinal axis (centerline of the transfer tunnel), positive in the nominal DPS-APS thrust direction. The z-axis is parallel to the centerline of the exit hatch and directed forward as seen by an astronaut looking out the main windows. The y-axis completes the right-hand triad.

c. Navigation-Base Coordinate System.—These axes are essentially parallel to the axes of the Vehicle Coordinate System and are constructed from lines passing through the navigation base mounting points.

d. Stable-Member, or Platform, Coordinate System.—The orientation of this coordinate system with respect to the Basic-Reference Coordinate System defines the current stable-member inertial orientation. The axes of this coordinate system may be considered to be fixed to the stable member structure and move within the IMU on gimbals.

The current stable-member inertial orientation is stored in the AGC as a transformation matrix from the Basic-Reference Coordinate System to the Stable-Member Coordinate System; this matrix is called REFSMMAT. Of the many orientations that the stable member can assume, the four primary alignments are defined below and discussed in Section 7.2.2. All vectors refer to basic reference coordinates.

1. Preferred Alignment:

$$\underline{u}_{XSM} = \text{UNIT}\ (\underline{x}_B)$$
$$\underline{u}_{YSM} = \text{UNIT}\ (\underline{u}_{XSM} \times \underline{r})$$

or, if $\underline{r}$ parallel to $\underline{x}_B$ in LM,

$$\underline{u}_{YSM} = \text{UNIT}\ (\underline{u}_{XSM} \times \underline{v});$$

if $\underline{r}$ parallel to $\underline{x}_B$ in CM P40 and P41,

$$\underline{u}_{YSM} = \text{UNIT}\left[\underline{u}_{XSM} \times (\text{UNIT}\ \underline{r} + 0.125\ \text{UNIT}\ \underline{v})\right]$$
$$\underline{u}_{ZSM} = \underline{u}_{XSM} \times \underline{u}_{YSM},$$

where $\underline{u}_{XSM}$, $\underline{u}_{YSM}$, and $\underline{u}_{ZSM}$ are the stable-member unit vectors, $\underline{x}_B$ = vehicle x-axis at the desired vehicle attitude for propulsion system ignition, $\underline{r}$ = vehicle position vector at ignition, and $\underline{v}$ = vehicle velocity vector at ignition.

2. Nominal Alignment (local vertical):

for CSM:

$$\underline{u}_{XSM} = (\underline{u}_{YSM} \times \underline{u}_{ZSM})$$
$$\underline{u}_{YSM} = \text{UNIT}\ (\underline{v} \times \underline{r})$$
$$\underline{u}_{ZSM} = \text{UNIT}\ (-\underline{r});$$

for LM:

$$\underline{u}_{XSM} = \text{UNIT}\ (\underline{r})$$
$$\underline{u}_{YSM} = \text{UNIT}\ (\underline{v} \times \underline{r})$$
$$\underline{u}_{ZSM} = \underline{u}_{XSM} \times \underline{u}_{YSM}$$

where $\underline{r}$ and $\underline{v}$ represent the vehicle position and velocity at the time of alignment.

3. Landing-site Alignment:

$$\underline{u}_{XSM} = \text{UNIT}\ (\underline{r}_{LS})$$
$$\underline{u}_{YSM} = \underline{u}_{ZSM} \times \underline{u}_{XSM}$$
$$\underline{u}_{ZSM} = \text{UNIT}\left[(\underline{r}_c \times \underline{v}_c) \times \underline{u}_{XSM}\right],$$

where $\underline{r}_{LS}$ is the lunar landing-site vector at the predicted landing time, and $\underline{r}_c$ and $\underline{v}_c$ are the CSM position and velocity vectors.

4. During a rendezvous sequence, the following orientation can be obtained by using the procedure detailed in paragraph 7.2.2 (CSM P52).

Plane-change alignment:

$$\underline{X}_{SM} = \text{UNIT}\ (\underline{X}_{SM0} \cos 45 + \underline{Y}_{SM0} \sin 45)$$

prior to plane change, and

$$\underline{X}_{SM} = \text{UNIT}\ (\underline{X}_{SM0} \cos 45 - \underline{Y}_{SM0} \sin 45)$$

following plane change;

$$\underline{Y}_{SM} = \text{UNIT}\ (\underline{Z}_{SM} \times \underline{X}_{SM})$$

$\underline{Z}_{SM} = \underline{Z}_{SM0}$, where the subscript (0) refers to the orientation existing before the current realignment.

The origin of the CSM and LM Stable-Member Coordinate System is nominally at the center of the stable member. In the following LM programs, however, the origin of this system is shifted to the moon's center of mass:

Lunar Landing Programs, P63, P64, P66, and P68;
Nominal Ascent, P12;
Abort Programs, P70 and P71.

e. Earth-Fixed Coordinate System.—The origin of this rotating system is at the earth's center of mass. The z-axis lies along the earth's true rotational, or polar, axis. The x-axis is along the line from the origin towards the intersection of the Greenwich meridian and the equatorial plane. The y-axis is in the equatorial plane and completes the right-hand triad.

f. Moon-Fixed Coordinate System.—This rotating system originates at the moon's center of mass. The z-axis is along the rotational axis of the moon, and the x-axis is along the line from the origin toward the intersection of the meridian of zero deg longitude and the equatorial plane of the moon (near the center of the moon's disk as seen from the earth). The y-axis is in the moon's equatorial plane and completes the right-hand triad.

g. Sextant-Base Coordinates (CM only).—The lines-of-sight (LOS) of the SXT and SCT are positioned by rotating a mirror in the SXT and SCT about a shaft axis and a trunnion axis. The shaft axes of both instruments are fixed at approximately 33 deg above the CM +z-axis in the CM x, z plane. When the mirror rotation about the shaft axis is at "zero", the trunnion axis is parallel to the CM y-axis. Mirror rotation about the trunnion axis then moves the LOS in the CM x, z plane only. When the trunnion rotation angle is at "zero", the LOS points along the shaft axis. The trunnion axis can be elevated from zero to about 50 degrees. Thus, rotating the shaft and elevating the trunnion allows the crew to acquire any target within a 100-deg cone (Figure 7.2.2-8). The shaft angle and trunnion angle then specify the direction of the LOS with respect to the optical unit assembly.

h. Alignment Optical Telescope Coordinates (LM only).—These coordinates relate AOT viewing positions (detents) to LM navigation base coordinates. The azimuth and elevation of the center of the field of view for each of the six detents is stored in the computer in navigation base coordinates. In coasting flight, a target LOS is determined by rotating the LM so

that the target image crosses an x and a y crosshair. These lines define two planes of known orientation relative to the navigation base. When an x and a y mark is taken, the intersection of these two planes can be calculated by the LGC to generate an LOS to the target. On the lunar surface, the LM cannot be rotated, and another technique is used to establish an LOS. By rotating the AOT reticle, the target is superimposed on a crosshair and then on a spiral pattern; these two measurements determine the location of the target within the AOT field of view (Figure 7.3.3-6). This latter technique can also be used during coasting flight.

7.1.3 IMU-Orientation Determination Techniques

The AGC's task of establishing and maintaining an inertial-attitude reference can now be stated in terms of the coordinate systems defined above. There are two basic problems to be solved by the alignment programs: (a) determine the stable member's axes relative to the Basic-Reference Coordinate System, i.e., determine the current REFSMMAT; and (b) determine the stable member's orientation relative to a desired inertial orientation (preferred, nominal, or landing site). Since the stable member will slowly drift away from the orientation stored in REFSMMAT, item b also includes the problem of determining the current stable-member orientation relative to the orientation stored in REFSMMAT. Once the stable member's orientation is known relative to the desired orientation, it can be pulse torqued into the desired orientation.

The technique used by the AGC to determine the current REFSMMAT is as follows:

a. Using the SXT or AOT, measure an LOS to two celestial bodies in navigation-base coordinates.* Transform the measured vectors to stable-member coordinates using the gimbal angles to relate navigation-base coordinates to stable-member coordinates.
b. Obtain the basic-reference coordinates for the same two celestial bodies from storage, calculation, or astronaut DSKY entry.
c. Use the difference between the stable-member coordinates and the basic-reference coordinates to calculate and store REFSMMAT.

An extension of this technique is used to determine the stable member's orientation relative to a desired inertial orientation:

*In P57, other measurements can be made instead of celestial body sightings. Refer to paragraph 7.3.3.

a. As before, measure two LOS in navigation-base coordinates and transform them to stable-member coordinates.

b. Obtain the basic-reference coordinates for the same two targets.

c. Convert the targets' basic-reference coordinates to vectors expressed in terms of the desired stable-member coordinates.

d. Use the difference between the present and desired stable-member coordinates of the targets to calculate the gyro torquing angles required to torque the stable member into alignment with the desired orientation.

In the CSM, the current REFSMMAT is obtained from celestial body sightings taken during P51 or P53; stable-member realignment is accomplished using P52 or P54. For the LM in flight, P51 and P52 serve the same functions as the corresponding CSM programs. On the lunar surface, all IMU alignment functions are accomplished by P57.

In accomplishing the steps listed above, all alignment programs have in common the following operation, which calculates the relative orientation of two coordinate systems: given two vectors, each expressed in two coordinate systems, compute the coordinate axes of one system expressed in terms of the other coordinate system. Consider P51 as an example and refer to Figure 7.1-4. The unit vectors $\underline{A}'$ and $\underline{B}'$ in Figure 7.1-4a represent lines of sight to two celestial bodies measured in the stable-member coordinate system $\underline{x}'$, $\underline{y}'$, $\underline{z}'$; $\underline{A}$ and $\underline{B}$ in Figure 7.1-4b represent the same two lines of sight as known in basic-reference coordinates $\underline{x}$, $\underline{y}$, $\underline{z}$. To compute REFSMMAT, the problem is to first find $\underline{x}'$, $\underline{y}'$, $\underline{z}'$ in terms of the unprimed coordinate system (Figure 7.1-4c).

This is accomplished by defining two new sets of orthogonal vectors, one in primed coordinates and one in unprimed coordinates, as follows (Figure 7.1-4d and e):

$$\underline{u}'_1 = \underline{A}'$$
$$\underline{u}'_2 = \text{UNIT}\,(\underline{A}' \times \underline{B}')$$
$$\underline{u}'_3 = \underline{u}'_1 \times \underline{u}'_2$$

and

$$\underline{u}_1 = \underline{A}$$
$$\underline{u}_2 = \text{UNIT}\,(\underline{A} \times \underline{B})$$
$$\underline{u}_3 = \underline{u}_1 \times \underline{u}_2.$$

The $\underline{x}'$ unit coordinate vector can now be constructed in unprimed coordinates as a vector sum of its components along $\underline{u}_1$, $\underline{u}_2$, and $\underline{u}_3$:

$$\begin{aligned}\underline{x}' \text{ (in unprimed coordinates)} &= (\underline{x}' \bullet \underline{u}'_1)\,\underline{u}_1 + (\underline{x}' \bullet \underline{u}'_2)\,\underline{u}_2 \\ &\quad + (\underline{x}' \bullet \underline{u}'_3)\,\underline{u}_3 \\ &= u'_{1x'}\,\underline{u}_1 + u'_{2x'}\,\underline{u}_2 + u'_{3x'}\,\underline{u}_3,\end{aligned}$$

where $u'_{1x'}$, $u'_{2x'}$, $u'_{3x'}$, represent the components of $\underline{u}'_1$, $\underline{u}'_2$, and $\underline{u}'_3$, respectively, along the x' axis. Similarly, for the y' and z' axes,

$$\underline{y}' = u'_{1y'}\,\underline{u}_1 + u'_{2y'}\,\underline{u}_2 + u'_{3y'}\,\underline{u}_3$$

$$\underline{z}' = u'_{1z'}\,\underline{u}_1 + u'_{2z'}\,\underline{u}_2 + u'_{3z'}\,\underline{u}_3.$$

By definition, REFSMMAT is the matrix which transforms a vector from basic-reference coordinates to stable-member coordinates. Therefore,

$$\text{REFSMMAT} = \begin{bmatrix} \underline{x}'^T \\ \underline{y}'^T \\ \underline{z}'^T \end{bmatrix}$$

An AGC routine called AXISGEN carries out the above calculations. In P51 and P53, the inputs to AXISGEN are the four line-of-sight vectors; two are in stable-member coordinates and two are in basic-reference coordinates.* Two lines of sight are measured in sextant-base or AOT coordinates, then transformed into navigation-base coordinates, and finally, using the IMU gimbal angles, transformed into stable-member coordinates suitable for AXISGEN input. The other two lines of sight are obtained in basic-reference coordinates from stored knowledge of the celestial bodies' inertial coordinates. The output of AXISGEN is used as REFSMMAT.

In P52, P54, and P57, the AGC must compute the desired orientation of the stable-member axes with respect to the present Stable-Member Coordinate System. In this case, the inputs to AXISGEN are two vectors describing the LOS to two

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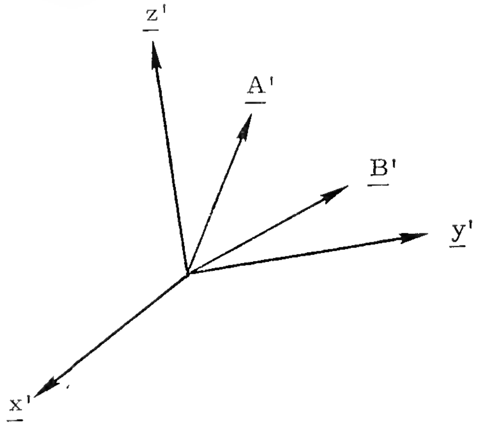
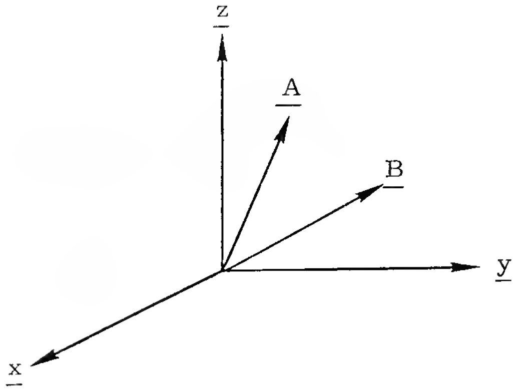
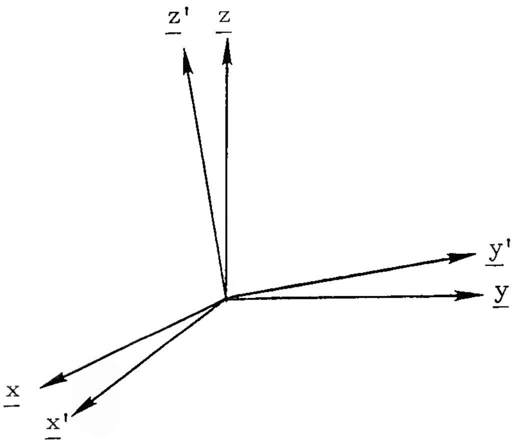
*In P57, AXISGEN can have other inputs; refer to paragraph 7.3.3.



a. Vectors A and B described in primed coordinate system.

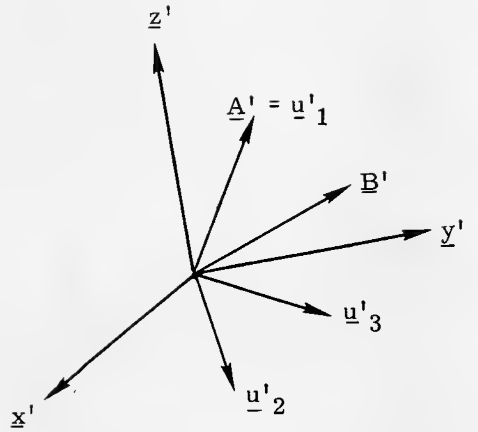


b. Vectors A and B described in unprimed coordinate system.

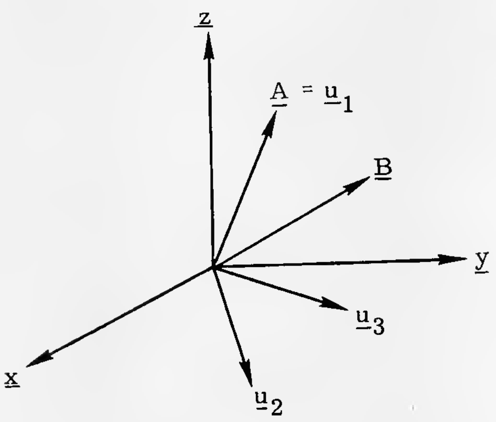


c. Primed coordinate system described in unprimed coordinate system.

Figure 7.1-4. Coordinate Axes Generator (Sheet 1 of 2)



d. Orthonormal vectors generated from $\underline{A}'$ and $\underline{B}'$; primed axes are resolved into their components along $\underline{u}'_1$, $\underline{u}'_2$, $\underline{u}'_3$.



e. Orthonormal vectors generated from $\underline{A}$ and $\underline{B}$; primed axes are constructed in unprimed coordinates from their components along $\underline{u}_1$, $\underline{u}_2$, $\underline{u}_3$.

Figure 7.1-4. Coordinate Axes Generator (Sheet 2 of 2)

celestial bodies in present stable-member coordinates and two vectors describing the same LOS in desired stable-member coordinates. Figure 7.1-5 shows the processing of the four LOS vectors before AXISGEN input. If the target is a star, its basic-reference vector is obtained directly from AGC memory. If the target is the sun, earth, or moon, the AGC calculates its basic-reference vector. The astronaut must load the basic-reference vector for all other planets via the DSKY.

The general sequence of computer and ISS operations during the realignment programs is as follows (refer to Figure 7.1-6):

a. The astronaut selects a desired inertial orientation for the stable member.
b. The AGC calculates the gimbal angles corresponding to the desired stable-member orientation.
c. If the desired gimbal angles are satisfactory to the astronaut, the AGC realigns the stable member by using the ISS coarse-align mode. The stable member has now been positioned to within about one deg of the desired inertial orientation.*
d. The astronaut takes sightings on two celestial bodies to enable the AGC to precisely determine the difference between the present and desired orientations and to compute the required torquing angles.
e. Using the ISS fine-align mode, the stable member is pulse torqued into the desired orientation, with a precision of 40 arc sec.

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*As an alternative to coarse alignment, the stable member can be pulse torqued at this stage of the program. This can be done if the astronaut is willing to spend the time required for pulse-torquing through significant angles. Pulse-torquing provides increased confidence in the ensuing automatic optics positioning for celestial body sightings, and provides sufficiently accurate realignment for such maneuvers as out-of-plane burns.

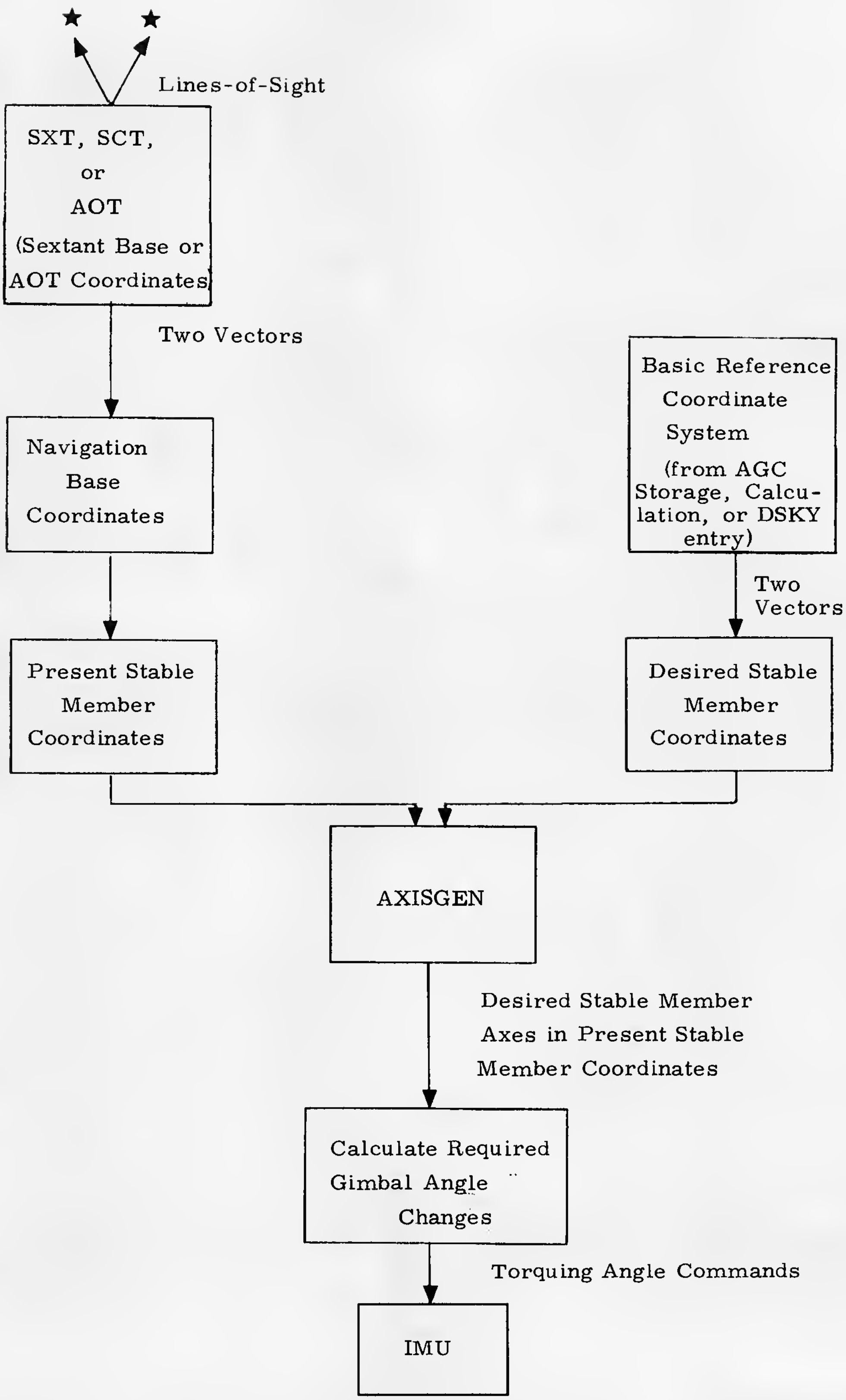

Figure 7.1-5. AXISGEN Inputs for Realignment Programs

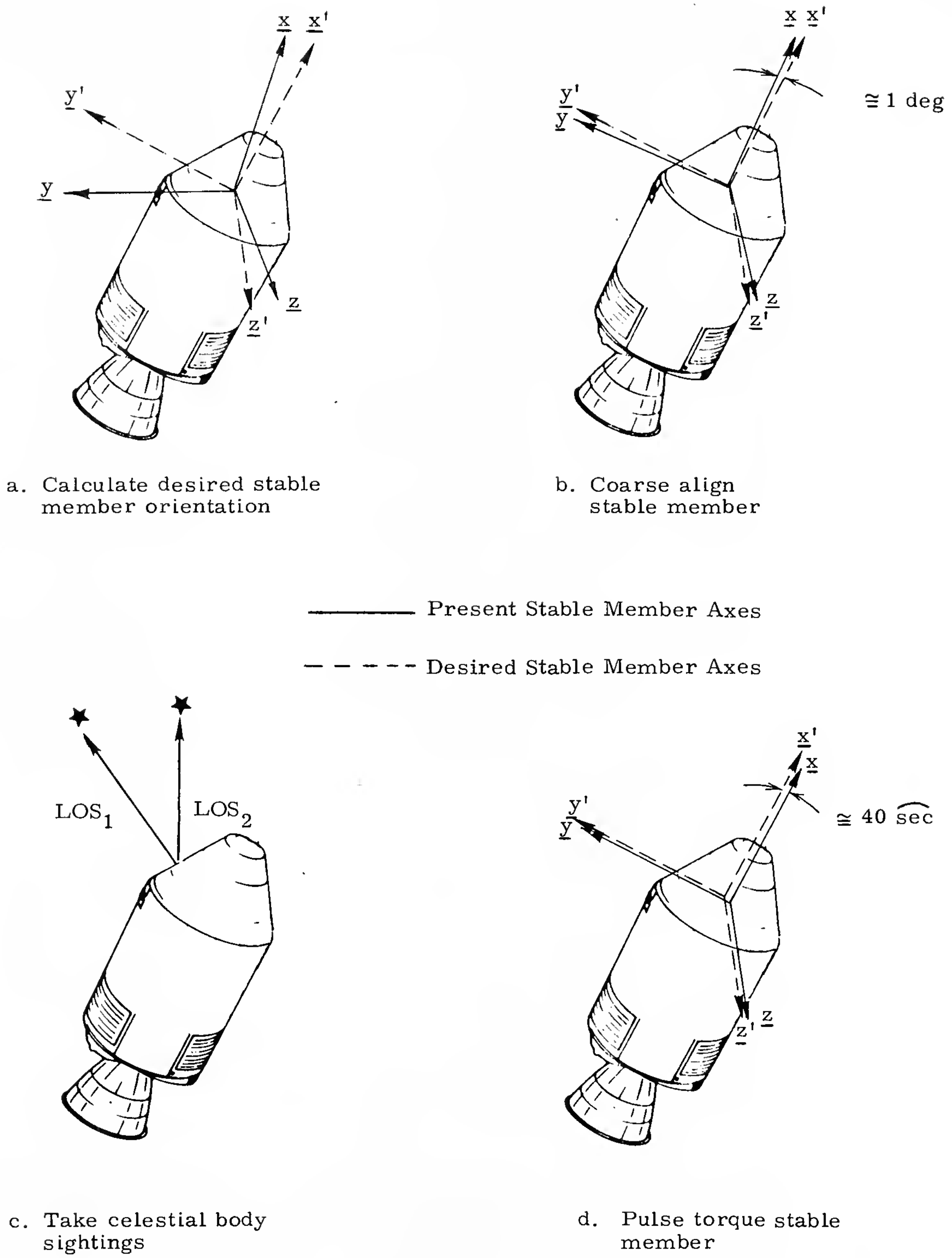

Figure 7.1-6. IMU Realignment Sequence

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7.2 CMC ALIGNMENT PROGRAMS

Figure 7.2-1 lists Command Module Computer (CMC) alignment program activity during a typical CSM mission. Note that the IMU Orientation Determination Program (P51) is not shown. The original plan was that the ISS should be turned off when not in use and P51 be performed to determine REFSMMAT after each ISS power-up. Current procedures, however, leave the CSM ISS on during the entire mission. P51 is needed only in event of an unplanned loss of inertial reference, such as an ISS power-down or a gimbal lock.

Several REFSMMATs are used by the CSM during the mission. The stable-member orientations that they describe are chosen to minimize the possibility of gimbal lock during planned SPS and RCS burns and to provide the most convenient orientation for the flight director attitude indicator (FDAI). The stable-member orientations are described here (refer also to Figure 7.2-1):

a. Launch-pad orientation (launch through translunar injection)—stable member X- and Y-axes normal to pad local-vertical; X-axis aligned along launch azimuth, pointing downrange; Z-axis toward earth's center.

b. Passive thermal control (PTC) orientation (translunar coast, transearth coast, and midcourse corrections)—stable-member X-axis in the plane of the ecliptic and perpendicular to the earth-moon line projection in the ecliptic plane; Z-axis perpendicular to ecliptic plane and directed south; Y-axis completes the right-hand triad. (At beginning of PTC, spacecraft maneuvers to FDAI display of 0-deg roll, 90-deg pitch, and 0-deg yaw.)

c. Landing-site orientation (lunar-orbit injection through transearth injection)—stable-member X-axis along positive lunar-radius vector through landing site; Z-axis in direction of flight parallel to CSM orbital plane and perpendicular to X-axis; Y-axis completes the right-hand triad.

d. Plane-change orientation (used by CSM if required during rendezvous sequence)—obtained by pulse-torquing Z gyro 45 deg to avoid gimbal lock before subsequent plane-change maneuver. After plane-change, Z gyro is torqued so that original IMU orientation is recovered.

e. Entry orientation (uplinked five hours before earth entry)—places stable member in orientation such that, at FDAI indication of 0-deg roll, 180-deg pitch, 0-deg yaw, the CM is at the proper attitude for entry at entry interface (wings level, local horizontal, heatshield forward, lift up, heads down).

f. Preferred orientation—this REFSMMAT is used for propulsion system burns when a gimbal lock might be caused by keeping the stable member aligned to some other REFSMMAT with the spacecraft at the required burn attitude. For example, in preparation for a lunar-orbit plane-change SPS burn, the stable member is realigned from the landing-site REFSMMAT to an uplinked preferred REFSMMAT. Also, if the required middle-gimbal angle for a midcourse correction is greater than 60 deg, a preferred REFSMMAT will be used for the burn instead of the PTC REFSMMAT. The preferred REFSMMAT can be chosen so that the FDAI reads "0,0,0" at the desired attitude.

APPROXIMATE TIME FROM LAUNCH (HR:MIN)	EVENT
00:00	LIFTOFF
00:10	EARTH PARKING ORBIT INSERTION
00:25	OPTIONAL P52 REALIGN TO LAUNCH PAD REFSMMAT (OPTION 3) VOICE TORQUING ANGLES TO GROUND FOR DRIFT CHECK.
01:50	BEGIN TLI PREPARATION
02:35	TLI IGNITION
03:30	CSM/LM EJECTION FROM S-IVB
05:00	P52 REALIGN TO LAUNCH PAD REFSMMAT (OPTION 3). P23 CISLUNAR NAVIGATION
09:30	P52 REALIGN TO PTC REFSMMAT (OPTION 1)
11:30	MIDCOURSE CORRECTION-1 (TLI +9 HR)*
26:00	P52 REALIGN TO PTC REFSMMAT (OPTION 3)
30:30	MIDCOURSE CORRECTION-2 (TLI +28 HR)*
32:00	P23 CISLUNAR NAVIGATION
48:00	P52 REALIGN TO PTC REFSMMAT (OPTION 3)
54:00	P52 REALIGN TO PTC REFSMMAT (OPTION 3)
55:00	MIDCOURSE CORRECTION-3 (LOI-22 HR)*
58:00	LM FAMILIARIZATION
70:00	P52 REALIGN TO PTC REFSMMAT (OPTION 3)

APPROXIMATE TIME FROM LAUNCH (HR:MIN)	EVENT
72:00	MIDCOURSE CORRECTION-4 (LOI-5 HR)*
75:00	P52 REALIGN TO LANDING SITE ORIENTATION (UPLINKED AS PREFERRED, OPTION 1)
77:00	P40, SPS THRUST; LOI
81:00	P52 REALIGN TO LANDING SITE ORIENTATION (OPTION 3)
81:40	DOI MANEUVER TO BAILOUT ATTITUDE
82:50	P52 REALIGN TO LANDING SITE ORIENTATION (OPTION 3)
94:45	UPLINK TO CSM NEW LANDING SITE REFSMMAT
95:00	P52 REALIGN TO NEW LANDING SITE ORIENTATION (OPTION 1)
96:30	DOCKED LM IMU COARSE ALIGN
97:00	DOCKED LM IMU FINE ALIGN
98:15	UNDOCKING AND SEPARATION

*<u>NOTE:</u> IF THE REQUIRED MIDDLE GIMBAL ANGLE FOR ANY BURN IS GREATER THAN 60 DEG, GROUND WILL UPLINK PREFERRED REFSMMAT. P52 WILL REALIGN TO PREFERRED, BURN WILL BE MADE, AND P52 WILL REALIGN BACK TO UPLINKED PTC REFSMMAT.

Figure 7.2-1 Timeline of Typical CSM P52 Activity (Sheet 1 of 3)

APPROXIMATE TIME FROM LAUNCH (HR:MIN)	EVENT
99:00	P52 REALIGN TO LANDING SITE ORIENTATION (OPTION 3)
99:40	CSM ORBIT CIRCULARIZATION MANEUVER
101:00	P52 REALIGN TO LANDING SITE ORIENTATION (OPTION 3)
102:30	LM POWERED DESCENT INITIATION
102:42	TOUCHDOWN

APPROXIMATE TIME FROM LM TOUCHDOWN (HR:MIN)	EVENT
00:00	TOUCHDOWN
00:15	P52 REALIGN TO LANDING SITE ORIENTATION (OPTION 3)
01:45	P22 LANDMARK TRACKING
07:30	UPLINK TO CSM PREFERRED REFSMMAT FOR CSM PLANE CHANGE
08:00	P52 REALIGN TO PREFERRED REFSMMAT (OPTION 1)
09:20	P40, PLANE CHANGE
10:00	UPLINK TO CSM LIFT-OFF (LANDING SITE) REFSMMAT; P52 PULSE TORQUE TO LIFT-OFF REFSMMAT

APPROXIMATE TIME FROM LM LIFTOFF (HR:MIN)	EVENT
-03:40	P52 REALIGN TO LIFT-OFF REFSMMAT (OPTION 3)
-02:00	P22 LANDMARK SIGHTINGS
-01:30	P52 REALIGN TO LIFT-OFF REFSMMAT (OPTION 3)
-00:10	P22 LM TRACKING IN SXT
-00:00	LM LIFT-OFF
00:20	P52 REALIGN TO LIFT-OFF REFSMMAT (OPTION 3); P20 RENDEZVOUS NAVIGATION; P32 TARGET CSI
02:00	CDH
02:45	TPI
03:45	DOCKING

APPROXIMATE TIME FROM (EARTH) LAUNCH (HR:MIN)	EVENT
143:00	LM JETTISON
147:00	LM LUNAR IMPACT
153:00	UPLINK TO CSM PLANE-CHANGE REFSMMAT; P52 REALIGN TO PLANE-CHANGE REFSMMAT (OPTION 1)

Figure 7.2-1 Timeline of Typical CSM P52 Activity (Sheet 2 of 3)

APPROXIMATE TIME FROM (EARTH) LAUNCH (HR:MIN)	EVENT
154:30	PLANE CHANGE; UPLINK TO CSM LANDING SITE REFSMMAT; P52 REALIGN TO LANDING SITE REFSMMAT (OPTION 1)
161:00	P52 REALIGN TO LANDING SITE REFSMMAT (OPTION 3)
163:20	P52 REALIGN TO LANDING SITE REFSMMAT (OPTION 3)
165:30	P52 REALIGN TO LANDING SITE REFSMMAT (OPTION 3)
167:00	P40 SPS THRUST
167:30	TEI
170:00	UPLINK TO CSM PTC REFSMMAT; P52 REALIGN TO PTC REFSMMAT (OPTION 1)

PERIODIC P52 REALIGN TO PTC REFSMMAT (OPTION 3) BEFORE EACH TRANSEARTH MIDCOURSE CORRECTION. SEE NOTE, SHEET 1.

APPROXIMATE TIME FROM ENTRY INTERFACE (HR:MIN)	EVENT
-05:00	UPLINK TO CSM ENTRY REFSMMAT
-04:00	P52 REALIGN TO ENTRY REFSMMAT (OPTION 1)
-03:00	LAST MIDCOURSE CORRECTION
-01:45	MANEUVER TO ENTRY ATTITUDE
-01:30	P52 REALIGN TO ENTRY REFSMMAT (OPTION 3)
-00:00	ENTRY INTERFACE

Figure 7.2-1 Timeline of Typical CSM P52 Activity (Sheet 3 of 3)

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7.2.1 P51, IMU Orientation Determination Program—CMC

The IMU Orientation Determination Program (P51) is used during free fall to determine the present stable member orientation with respect to the Basic Reference Coordinate System and the associated REFSMMAT. This is accomplished by sighting on two navigation stars, or known celestial bodies, with the scanning telescope (SCT) or the sextant (SXT). [Only the star line of sight (SLOS) is used when the crew performs celestial body sightings and marking using the SXT.] Determining the stable member orientation with respect to the Basic Reference Coordinate system requires the transformation matrix REFSMMAT.

The astronaut acquires the desired celestial bodies by maneuvering the spacecraft and the optics until the bodies are visible in the optical devices. Upon acquiring the celestial bodies, he performs the sighting by centering the SCT or SXT SLOS on the celestial body, and then depressing the MARK pushbutton. Taking the mark causes the measurement time, the optics CDU angles, and the IMU gimbal angles to be recorded in the CMC. The LOS vector in IMU stable member coordinates is also computed.

When the sighting, marking, and computations have been accomplished on two celestial bodies, the CMC computes the angle between the two vectors. This angle is then compared with the angle between the unit LOS vectors, in basic reference coordinates, stored in the CMC; the difference is displayed to the crew in order that they can either accept the information, or reject it and repeat the orientation determination.

The displays during the IMU orientation determination are listed on Table 7.2.1-I.

7.2.1.1 Related Routines

P51 has the following two related routines:

a. The Sighting Mark Routine (R53)
b. The Sighting Data Display Routine (R54)

The Sighting Mark Routine (R53) is called automatically by P51 and is used to request and process marks (using the SCT and SXT) on the celestial bodies determined by the crew. The routine causes five angles (three inertial and two optical) and the mark time to be stored. The routine also determines LOS vectors to the celestial body if the celestial body is the sun, earth, or moon (code 46, 47, or 50 respectively). R53 also obtains stored information from the star ephemeris and allows the crew to load planet position vectors by putting up a flashing VERB 06 NOUN 88 display.

TABLE 7. 2. 1-I

PROGRAM DISPLAYS (CSM P51)

DSKY	Initiated by	Purpose	Condition	Register(s)
FL V06 N88	P51	Display Planet Position Vector	XPL YPL ZPL	R1 .xxxxx R2 .xxxxx R3 .xxxxx
FL V01 N71	R53	Display Celestial Body Code	00 (any planet) 01/45 star (from celestial body code list) 46 sun 47 earth 50 moon	R1 oooxx octal R2 Blank R3 Blank
FL V50 N25	P51 and R53	Request Please Perform 1 Celestial body Acquisition 2 Terminate Mark Sequence	00015 00016	R1 oooxx R2 Blank R3 Blank
FL V51 N blank *	R53	Request Please Mark	—	R1 Blank R2 Blank R3 Blank
V41 N22	P51	Display Coarse align Verb/ICDU angles	All zeros for coarse align	R1 00000 R2 00000 R3 00000
FL V06 N05	R54	Display Sighting Angle Difference	Difference between actual and measured star angles	R1 xxx. xx R2 Blank R3 Blank

*If after a MARK, the crew keys MARK REJ with FL VERB 50 NOUN 25 (R1, 00016) displayed, the FL V51 N25 (R1, 00016) will reappear to request a new MARK.

The Sighting Data Display Routine (R54) calculates and displays the difference angle between the actual (stored data) and measured (derived from mark angles) lines of sight.

7.2.1.2 Options

To complete P51, the astronaut has the option of using either the SCT or the SXT in determining the orientation. The procedure is the same for both, although using the SXT, which has a narrower field of view (1.8 degrees as compared to 60 degrees for the SCT), makes it more difficult to acquire celestial bodies. The normal procedure would be to acquire the star, planet, or other celestial body using the SCT; then to use the SXT SLOS for marking, because it provides greater accuracy (within 10 arc-sec) and a narrower field of view.

7.2.1.3 Logic Flow Description

P51 is selected by the crew by keying in VERB 37 ENTR 51 ENTR. (See Figure 7.2.1-1.) The crew should then monitor the DSKY to ensure that the program was properly entered. If the program was initialized without the Inertial Subsystem (ISS) being on, the PROG alarm light comes on. (See paragraph 7.2.1.4, alarm code 00210.) With the ISS on, the first display the crew sees is a flashing VERB 50 NOUN 25 with a 00015 code in register R1. (See Table 7.2.1-I.) This display requests the crew to "please perform celestial body acquisition." The astronaut must decide which two celestial bodies he will acquire, and either maneuver the CSM such that the bodies are visible in the SCT field of view or maneuver the CSM to position the inner gimbal axis in the preferred direction (stable-member X-axis in the thrust direction).

While maneuvering the CSM, however, the crew must ensure that gimbal lock is not impending by monitoring the Flight Director Attitude Indicator (FDAI) ball. Gimbal lock occurs when the middle gimbal angle exceeds ±85 degrees from zero. The gimbal lock warning light, however, is illuminated when the angle exceeds 70 degrees from zero. If 85 degrees is exceeded, the CMC automatically commands a coarse align to prevent gimbal oscillation. If gimbal lock is not impending and the astronaut does not desire to coarse-align the IMU, he can key in PRO and go directly into the Sighting Mark Routine (R53). If gimbal lock is impending, or if the astronaut desires, he can coarse-align the IMU to gimbal angles of 0, 0, 0. If the astronaut chooses the latter, he can key in ENTR. In this case a VERB 41 NOUN 22 is displayed on the DSKY (see Table 7.2.1-I) with zeros in all three registers. The NO ATT light comes on indicating that the IMU is in the process of zeroing all three gimbals

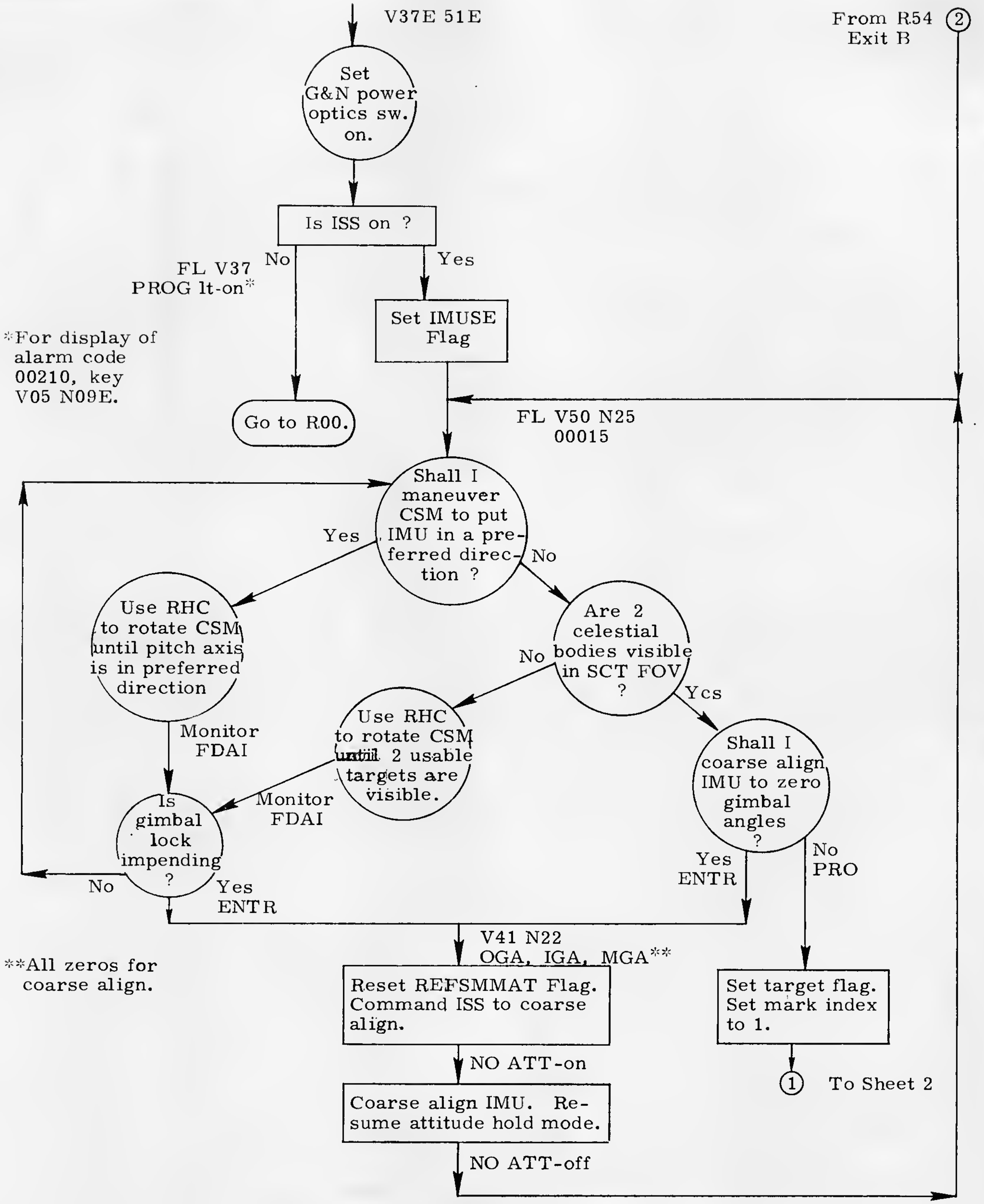

Figure 7.2.1-1 IMU Orientation Determination Program (CSM P51) (Sheet 1 of 3)

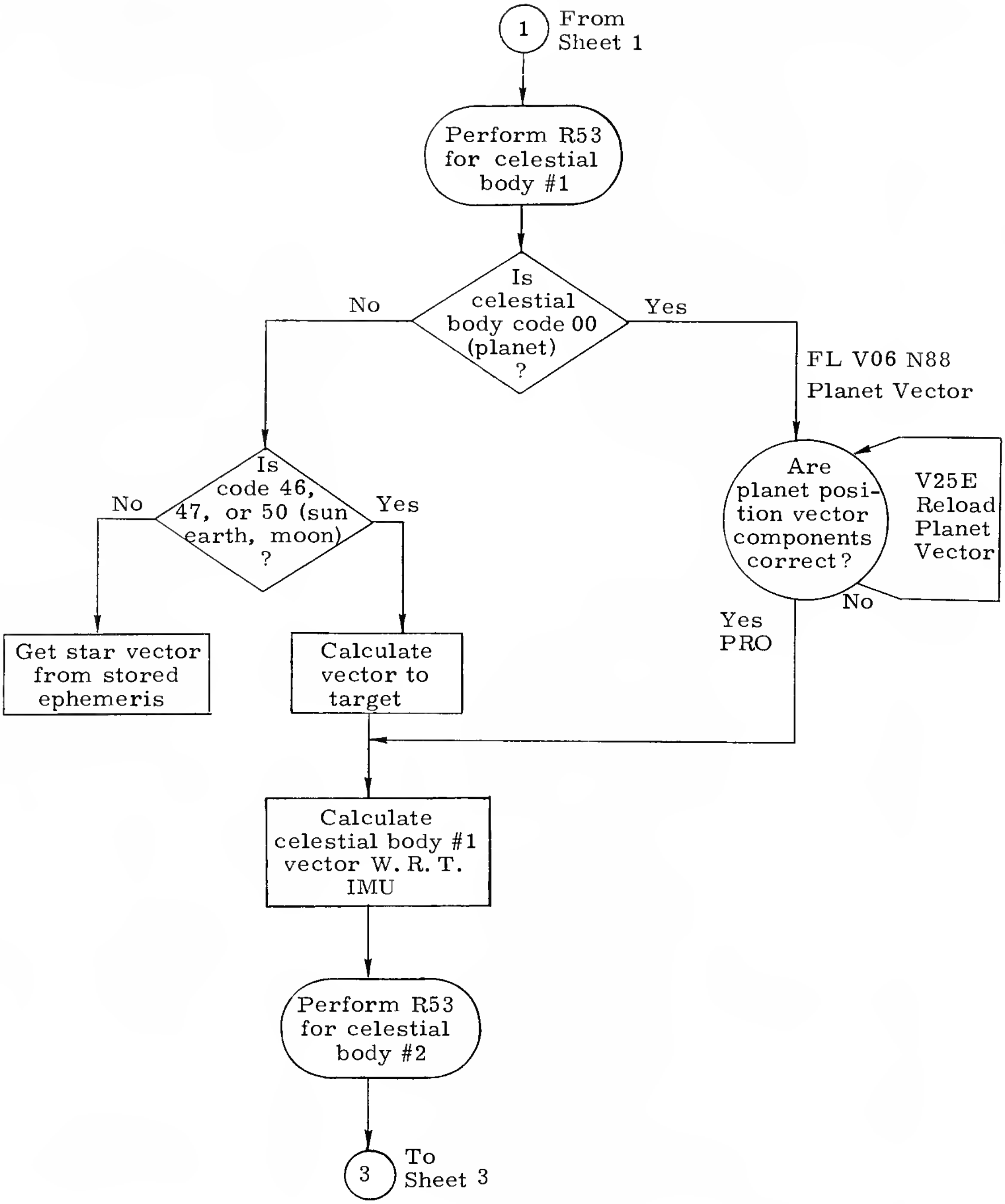

Figure 7.2.1-1 IMU Orientation Determination Program (CSM P51) (Sheet 2 of 3)

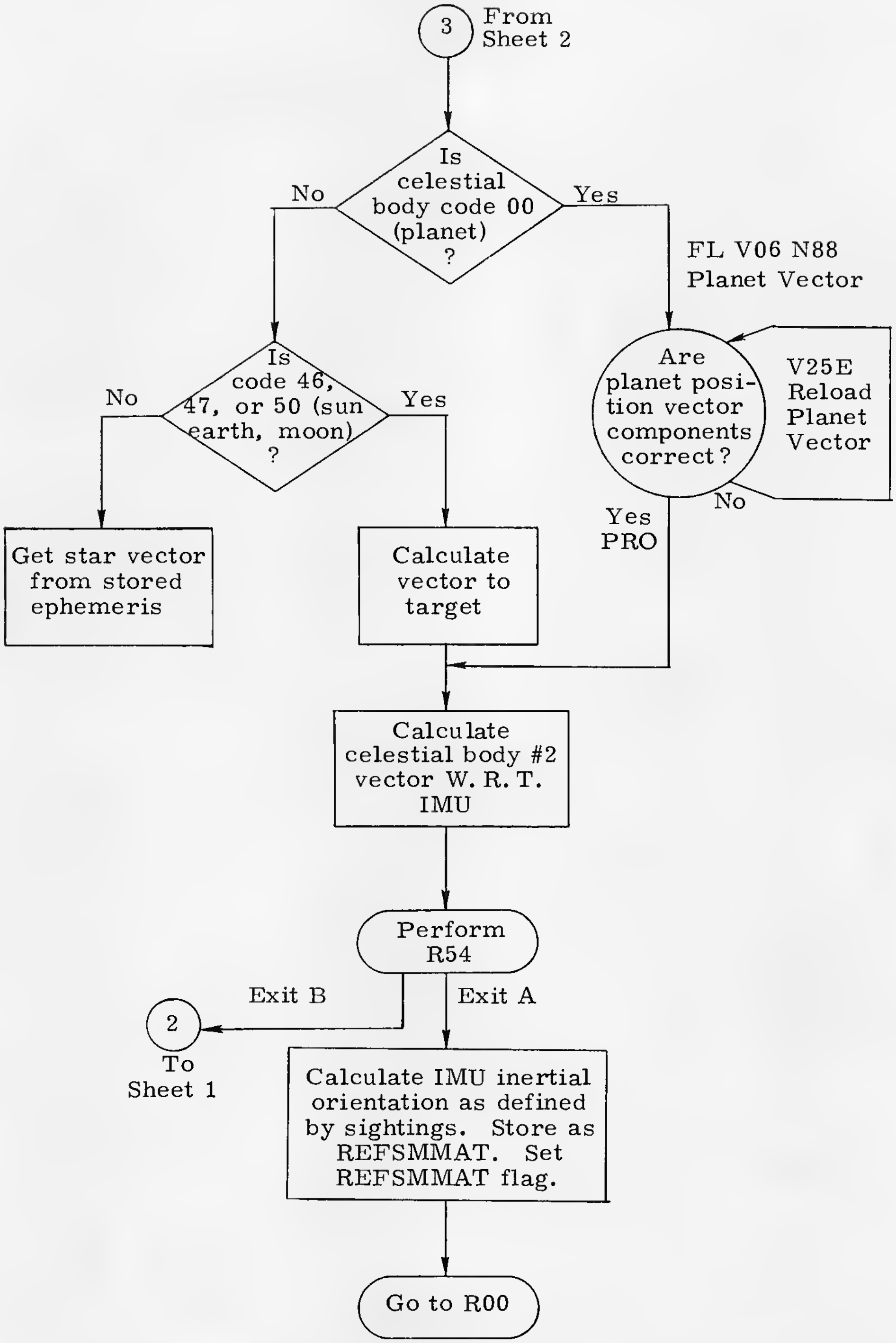

Figure 7.2.1-1 IMU Orientation Determination Program (CSM P51)
(Sheet 3 of 3)

(in the Coarse Align Mode). When the NO ATT light goes off, the VERB 50 NOUN 25 display comes up again, giving the astronaut the same choices he had the first time the display came up—except that the MGA is now zero. After manually acquiring the selected stars, the crew keys PRO, whch calls the Sighting Mark Routine (R53).

Flashing VERB 51 is displayed, requesting a "please mark." The crew should select the manual optics mode and, with the use of the Rotational Hand Controller (RHC), sight on the celestial body. (The manual optics mode is used because auto optics positioning is only used in P20, P22, P23, P24 and P52.) When the sighting is satisfactorily accomplished, the astronaut has the following three choices:

a. Depress the MARK REJECT pushbutton,
b. Depress the MARK pushbutton, or
c. Key in PRO.

Depressing the MARK REJECT pushbutton before any marks have been taken causes the PROG alarm light to come on and alarm code 00110 to be stored. (See paragraph 7.2.1.4.) If a mark has been taken and the MARK REJECT pushbutton is depressed, the last set of mark data (five angles and mark time) would be erased and the program would recycle to the flashing VERB 51 to take a new mark. The NOUN 25 (R1, 00016) display that follows a MARK remains up during a recycle FL VERB 51 display.

Depressing the MARK pushbutton stores the five angles (three ICDU and two OCDU) and the exact time the mark was taken. Flashing VERB 50 NOUN 25 (R1, 00016) then appears, requesting the crew to terminate mark taking. Upon the crew's PRO, the program proceeds to the FL VERB 01 NOUN 71 display of the celestial body code.

> <u>NOTE</u>.—If PRO is keyed in response to FL VERB 51, the display will remain up.

If the body code is incorrect, the crew should key in VERB 21 ENTR and load the proper code into R1. The program then checks the code to determine if: (a) it is a star, (b) a planet, or (c) if it is the sun, moon or earth.

If the code is a star (01/45 octal), the vector data are obtained from the ephemeris stored in the CMC. If the code is the sun, earth, or moon, 46, 47, or 50 respectively, the CMC computes the vector to the celestial body. If the code is 00, the program flashes VERB 06 NOUN 88 (see Table 7.2.1-I) requesting the crew to load the data for the x-, y-, and z-unit position vectors for the planet. In this case, the crew

can key in VERB 25 ENTR and load the proper x-, y-, and z-unit position vectors. Any proportional set of components can be loaded, but components of unit vectors are recommended.

Using the data computed from the marking sequence and the stored or known data, the CMC computes the measured vector to the celestial body with respect to present orientation of the IMU. This whole process is repeated for a second celestial body. Then the two vectors are tested by calling the Sighting Data Display Routine (R54).

The Sighting Data Display Routine (see Figure 7.2.1-2) calculates the angular difference between the actual (stored data) and the measured (derived from mark angles) LOS vectors and displays this difference angle via a flashing VERB 06 NOUN 05. If the angle difference is within acceptable limits, the astronaut should key PRO; the calling program, P51, calculates the IMU inertial orientation with respect to the celestial body coordinates defined by the two celestial bodies used for marking. These data are stored as the present platform orientation (REFSMMAT). If the angular difference is not within acceptable limits, the astronaut should key in VERB 32 ENTR (recycle) and return to the flashing VERB 50 NOUN 25 display at the start of P51, requesting celestial body acquisition (option code 00015), and the orientation determination is performed again.

7.2.1.4 Program Alarms

In addition to the anticipated outputs, the program displays a PROG alarm light and stores an alarm code for display to the crew. Keying in VERB 05 NOUN 09 allows the program to display an alarm code in R1, R2, and R3. (R1 displays the first alarm code to occur after the last RSET, R2 the second, and R3 the last.) Keying in RSET turns off the PROG alarm light on the DSKY if the condition causing the alarm has been corrected. After clearing the alarm condition and keying in RSET, keying in KEY REL allows the program to pick up from the point of interruption. The alarm codes and conditions causing them are as follows:

a. Alarm 00110 is displayed if a mark reject has been attempted with no marks to reject.
b. Alarm code 00114 is displayed if a mark has been made but not requested by the CMC.
c. Alarm 00121 indicates a mark was made at the time of a CDU switching transient, or vehicle rotation rate too high. Key RSET and continue normal operation.

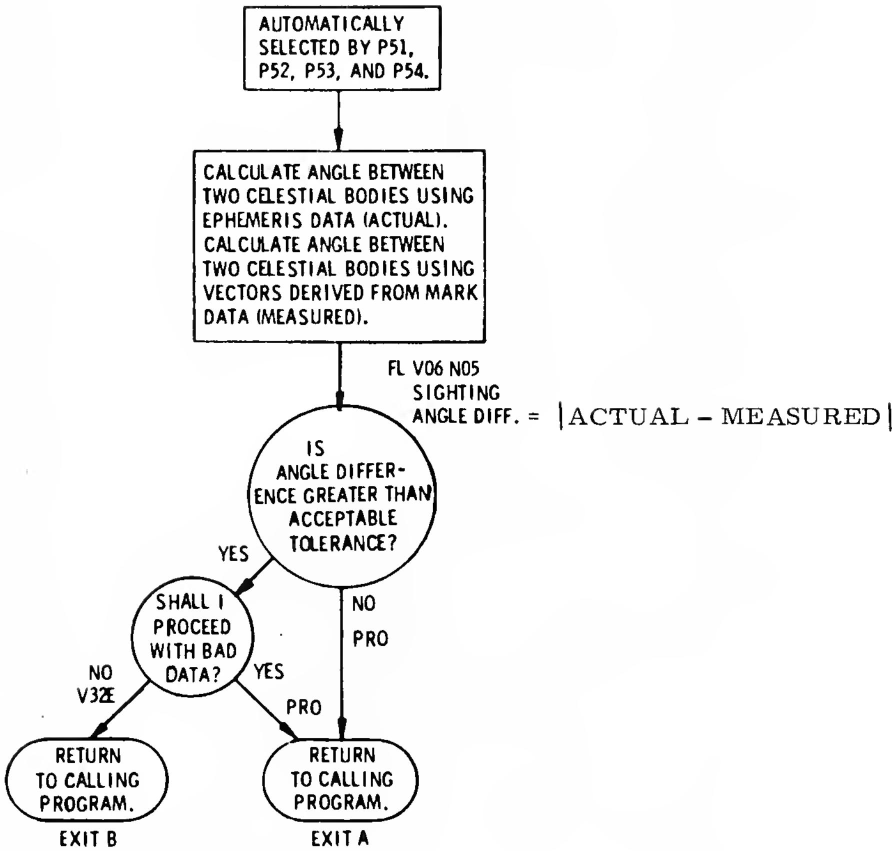

Figure 7. 2. 1-2 Sighting Data Display Routine (CSM R54)

d. Alarm code 00210 is displayed if the IMU is not operating when P51 is entered.

e. Alarm codes 00211 and 00217 are displayed if, at the end of coarse align ISS mode, the gimbals are not within 2 deg of the desired values.

f. Alarm code 31211 is displayed when there is an illegal interrupt of an extended verb.

If the ISS is not on, alarm code 00210 alerts the crew to turn on the IMU and, following a 15-minute warmup period, reselect P51 by keying in VERB 37 ENTR 51 ENTR. If, while in the process of sighting and marking on celestial bodies, the astronaut should press the MARK REJECT pushbutton and no marks have been taken to reject, the PROG alarm light comes on. The astronaut can key in VERB 05 NOUN 09 ENTR and determine, by monitoring the DSKY, that illumination of the PROG alarm light was caused by alarm code 00110.

Alarm code 00114 is stored if the MARK pushbutton has been depressed when the CMC is not flashing VERB 51.

7.2.1.5 Restrictions and Limitations

The restrictions and limitations peculiar to P51 are listed below.

a. For more accurate results in determining the IMU orientation, the crew should select celestial bodies that are greater than 30 degrees apart.

b. Before performing the IMU Orientation Determination Program, the IMU should be turned on and allowed to warm up for at least 15 minutes.

c. The celestial body codes selected should not be greater than 50, octal.

d. Only one mark per celestial body is required in order to complete P51.

e. Do not cage the IMU during flight as damage to the IRIGs may result.

7.2.1.6 Program Coordination and Procedures

There is really no best time to perform P51. It is strictly an orientation determination program and is used when it is necessary to calculate a new REFSMMAT. All programs that require REFSMMAT in their computational sequence might first require performance of P51.

If it is necessary to perform P51, enough time should be allowed for completion of the program (i.e., 15-minute IMU warmup, if necessary, plus time required by the crew for sighting and marking), prior to the time that the REFSMMAT is required.

7.2.1.7 Restarts

P51 is restart-protected.

7.2.2 P52, IMU Realign—CMC

The IMU Realignment Program is initiated by the CSM crew to move the IMU stable member from one known inertial orientation to another. P52 (Figure 7.2.2-1) serves two basic purposes: (a) to eliminate, as much as possible, the uncertainty in the knowledge of the stable member's orientation in inertial space arising from uncompensated gyro drift; and (b) to move the stable member into an inertial orientation that is more convenient than its currently known orientation. P52 calculates the orientation of the stable member with respect to a desired orientation (REFSMMAT, preferred, nominal, plane change, or landing site) and calculates the gimbal angle changes required to move the stable member into the desired orientation. To determine the orientation of the stable member with respect to the Basic Reference Coordinate System, the astronaut must execute P51, the IMU Orientation Determination Program (paragraph 7.2.1). To perform a plane-change realignment during a rendezvous sequence, refer to MINKEY procedures described in paragraph 7.2.2.5.

The coordinate systems used by P52 to define the stable member's orientation in relation to inertial space and in relation to the CSM are listed below:*

a. Basic Reference Coordinate System
b. Vehicle or Body Coordinate System
c. Navigation Base Coordinate System
d. Earth-Fixed Coordinate System
e. Moon-Fixed Coordinate System
f. Stable Member or Platform Coordinate System, which has five types of alignment:

    1. Preferred Alignment
    2. Nominal Alignment (local vertical)
    3. Landing Site Alignment
    4. REFSMMAT Alignment
    5. Plane-change Alignment

g. Sextant Base Coordinate System.

REFSMMAT is the name of an important coordinate transformation matrix used by the computer programs to define the orientation of the stable member. This is the

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*Refer to subsection 7.1 for a definition and discussion of coordinate systems and coordinate transformations.

matrix required to transform a vector from the Basic Reference Coordinate System to the Stable Member Coordinate system. When REFSMMAT is in storage and valid, the REFSMMAT flag is set, which informs all other programs that the inertial attitude of the stable member and the spacecraft is known by the computer. If REFSMMAT is invalid or is not known, the REFSMMAT flag is reset (cleared). Then any program which tests this flag (such as P20 or P30) will be informed that REFSMMAT is invalid.

Another matrix used, but not generated, by P52 is associated with the preferred stable member alignment defined above. This matrix describes the stable member orientation which will produce an FDAI indication of (0,0,0) for a powered maneuver attitude, and is either calculated and stored by P40 or P41 (the SPS and RCS Thrust Programs), or loaded into storage by P27 (the CMC Update Program). The preferred orientation can be used, for example, to establish an orientation for the vehicle roll axis for Passive Thermal Control (Barbecue). The PREFERRED flag is set or reset by the thrust programs, depending on whether or not a preferred alignment matrix has been computed by the CMC. (PREFERRED flag is also set after P52 calculates plane-change REFSMMAT.)

In the nominal, plane-change, and landing site alignments, the desired stable member orientation is calculated by P52. For the landing site alignment, the crew must supply to P52, via the DSKY, the time of alignment, and the coordinates of the lunar landing site, in latitude, half-longitude, and altitude. This information is required so that P52 can determine the inertial orientation of the landing site vector.

If the crew chooses nominal alignment, only the time of alignment is required, so that the program can extrapolate the spacecraft state vector up to the time specified, and use the extrapolated radius vector as a stable member minus z-axis alignment direction. Once the present and desired stable member orientations are known, P52 calculates the gimbal angle changes required to bring about the realignment.

At this point, for nominal and landing site alignments, the stable member can be repositioned in one of two ways: coarse alignment (ISS in coarse-align mode) to within about one deg of the exact alignment desired; or pulse torquing (ISS in fine-align mode) to within about one arc-min of the exact alignment desired. If the crew chooses coarse alignment, the inertial orientation of the stable member is then verified by sightings with the scanning telescope or sextant, and any small differences between the actual and desired stable member alignments are removed by pulse torquing the gyros through the angles required (fine alignment). For plane-change alignment, the stable member is repositioned by pulse-torquing.

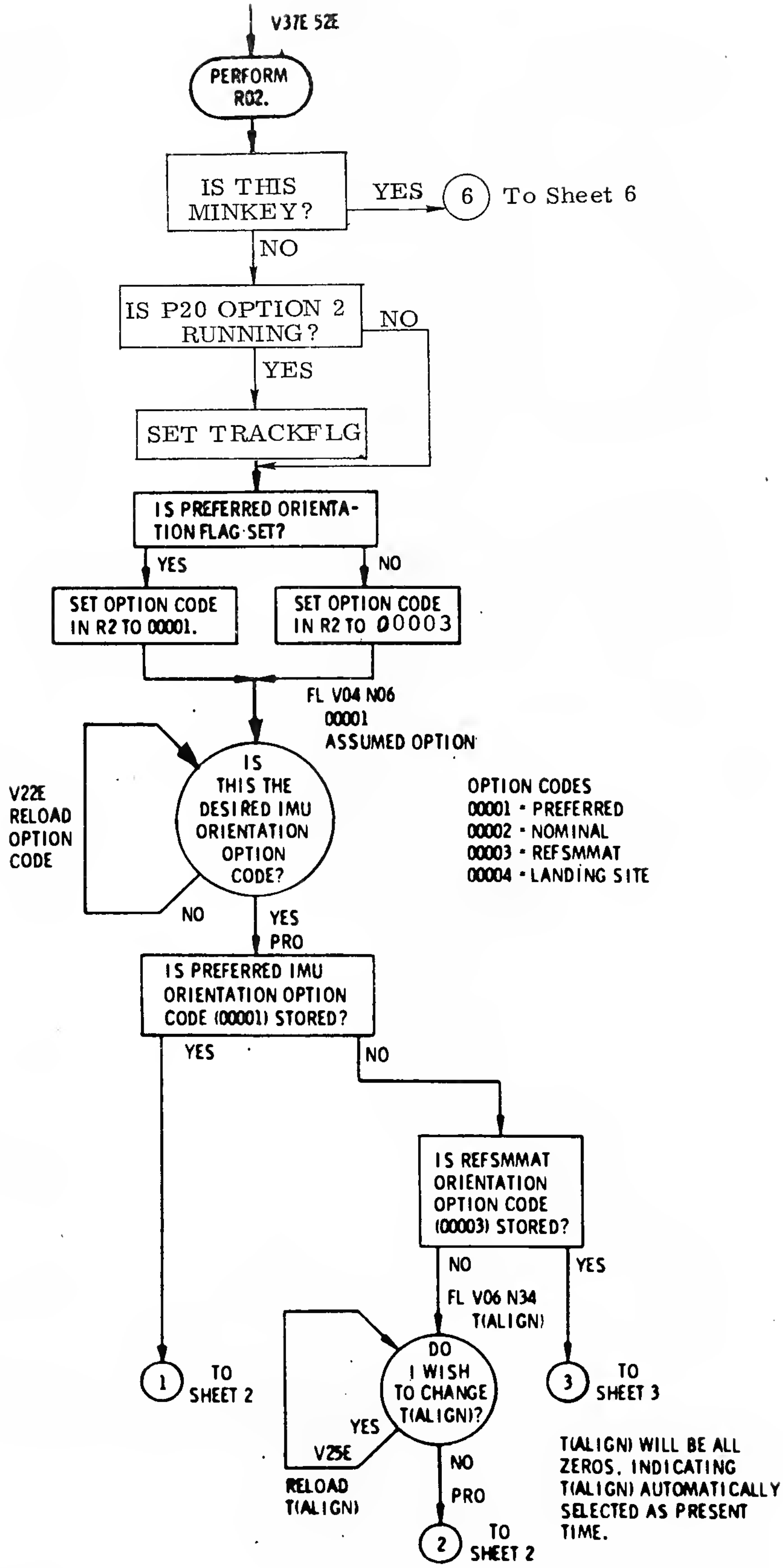


Figure 7.2.2-1. IMU Realign Program (CSM P52) (Sheet 1 of 7)

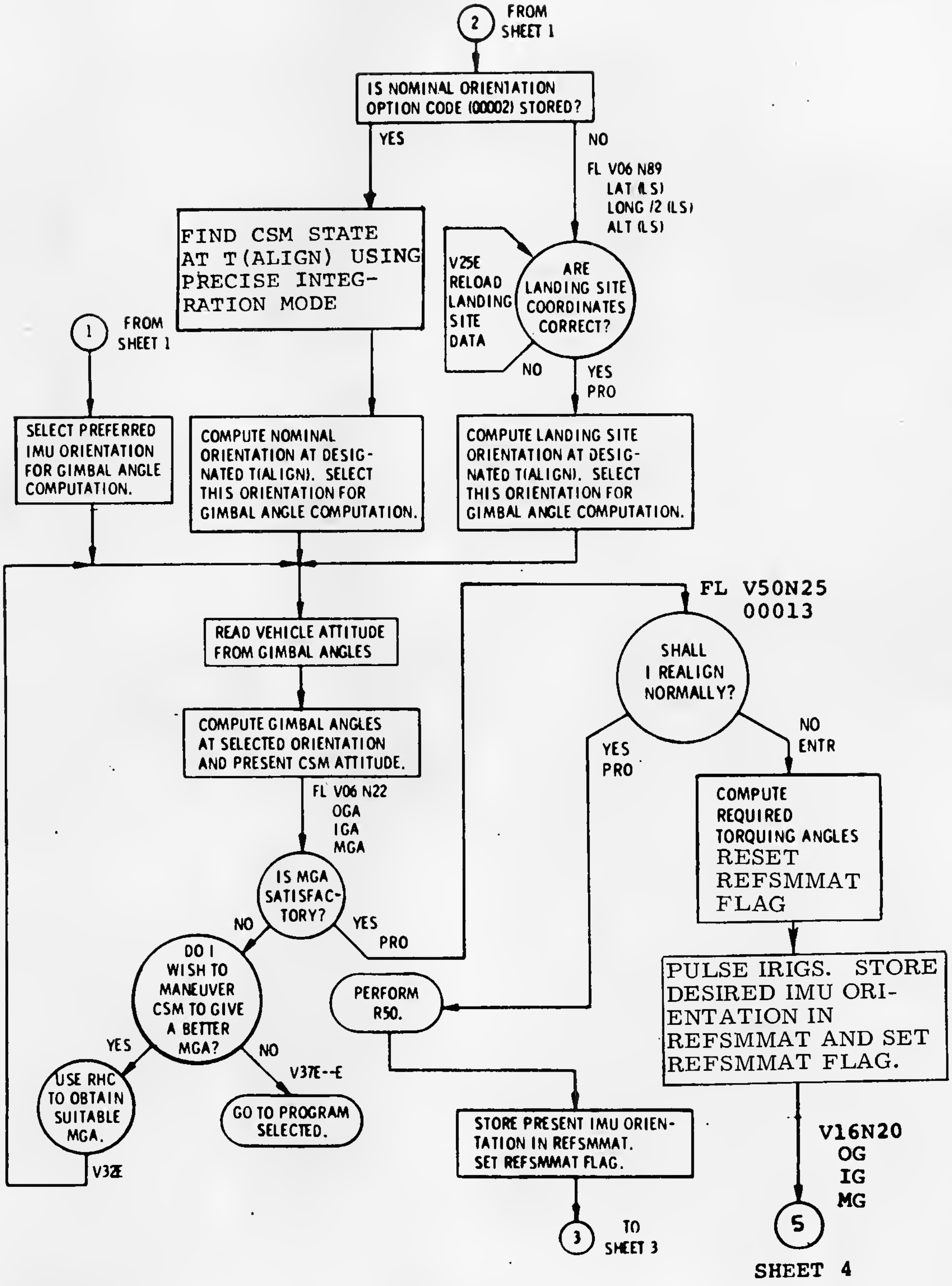


Figure 7. 2. 2-1. IMU Realign Program (CSM P52) (Sheet 2 of 7)

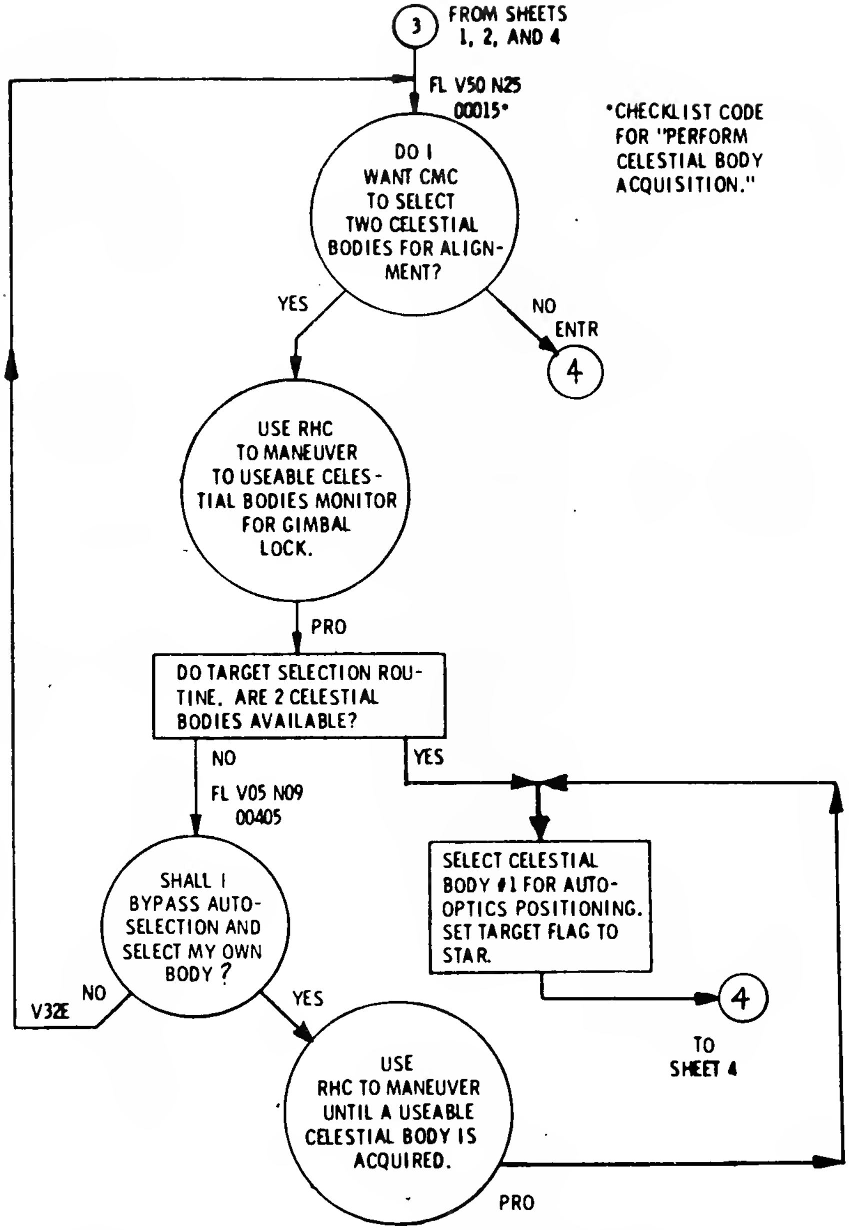


Figure 7.2.2-1. IMU Realign Program (CSM P52) (Sheet 3 of 7)

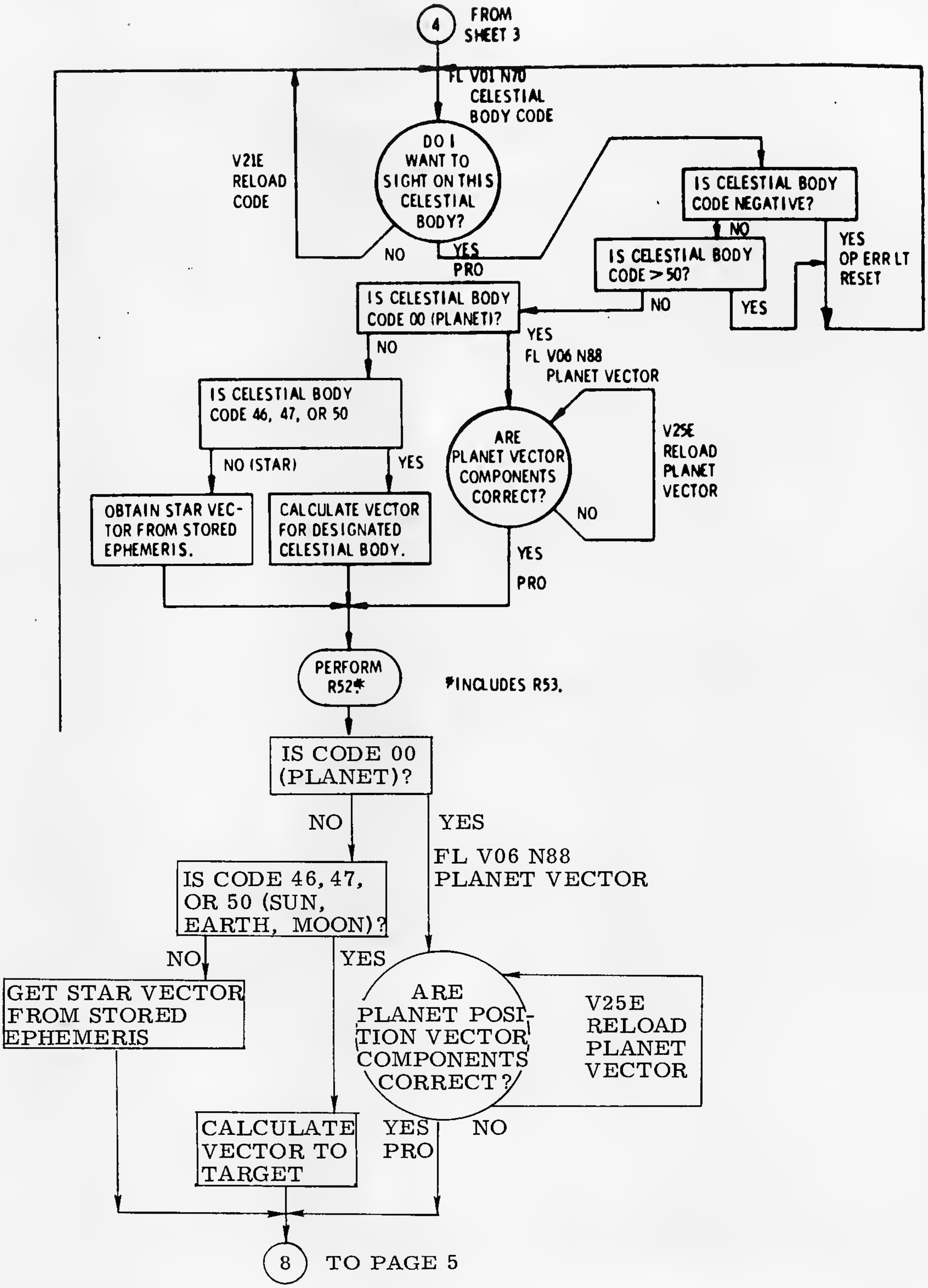


Figure 7. 2. 2-1. IMU Realign Program (CSM P52) (Sheet 4 of 7)

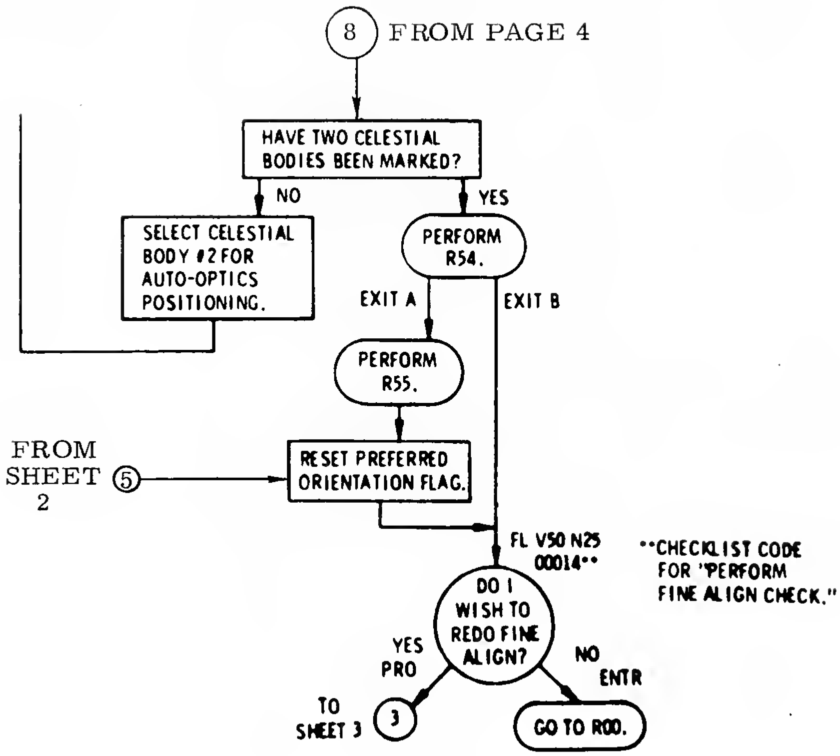


Figure 7.2.2-1. IMU Realign Program (CSM P52) (Sheet 5 of 7)

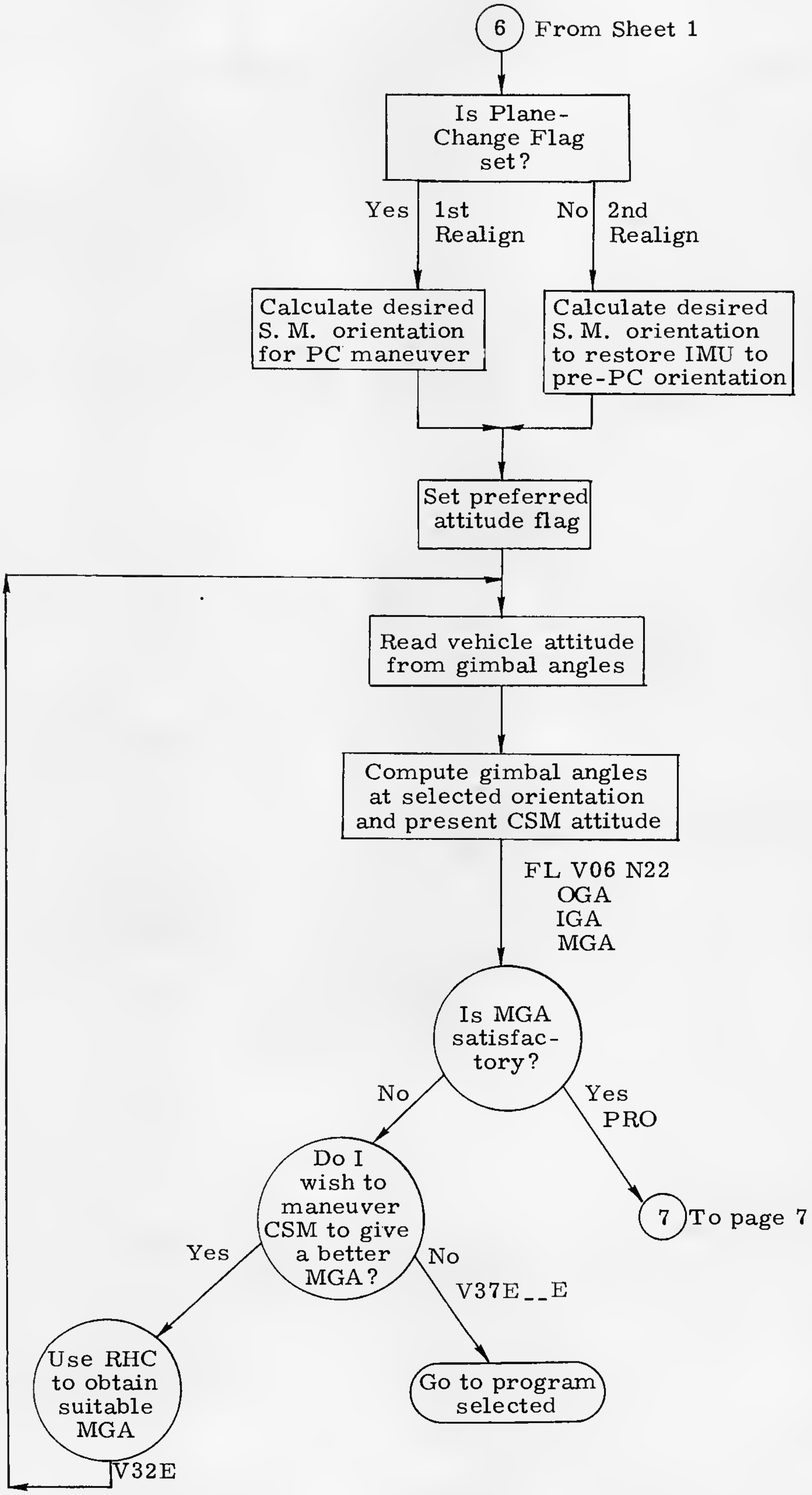


Figure 7.2.2-1. IMU Realign Program (CSM P52) (Sheet 6 of 7)

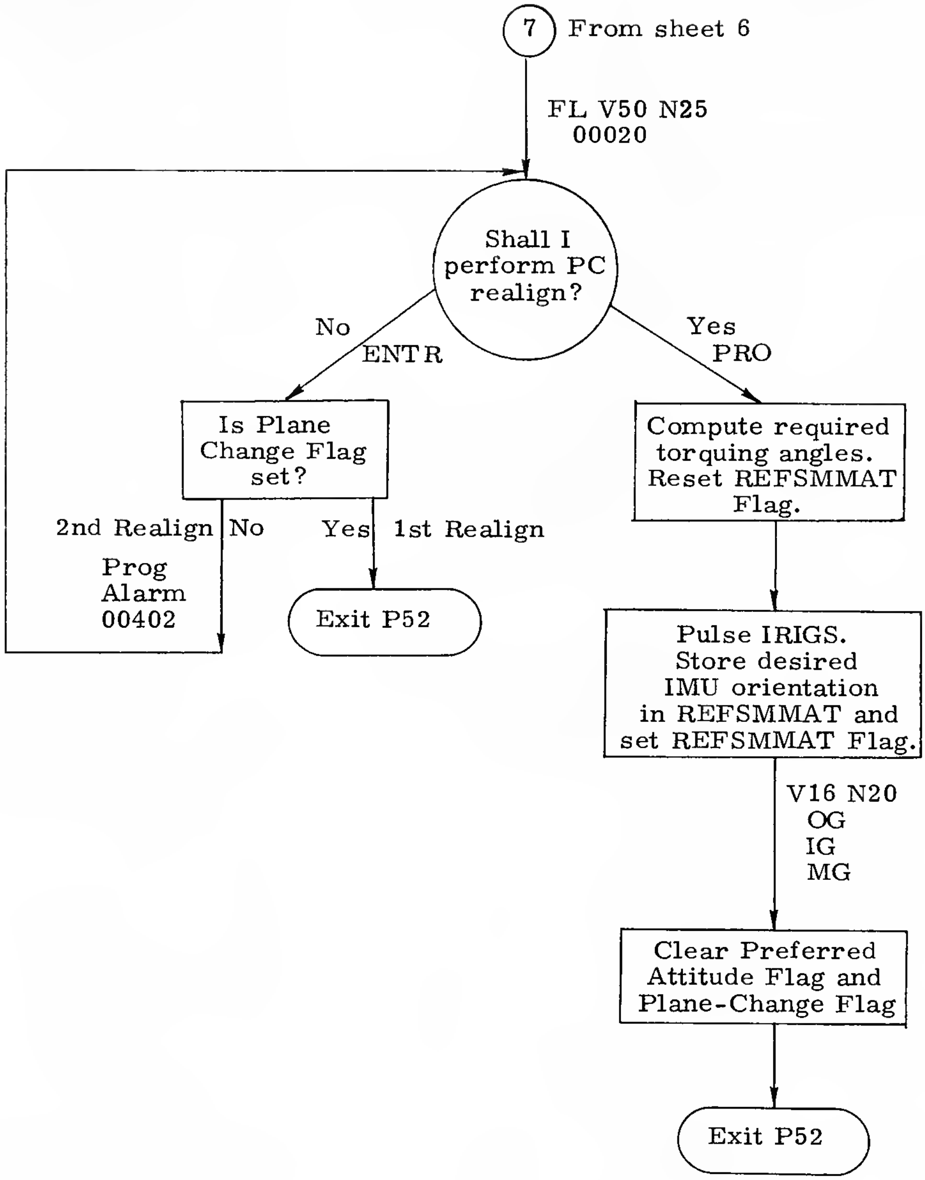


Figure 7.2.2-1. IMU Realign Program (CSM P52) (Sheet 7 of 7)

If the crew has chosen REFSMMAT alignment, coarse alignment is bypassed; the astronaut carries out only star sightings and fine alignment.

During P52, the crew sees displays of the gimbal angles, which are calculated corresponding to the alignment desired. If these angles indicate the risk that the stable member will be positioned into gimbal lock (middle gimbal angle of 85 deg or more), the crew can maneuver the spacecraft and recycle within the program to calculate the gimbal angles based on a new spacecraft attitude. (Refer to paragraph 7.2.2.3.2 below.)

In the event that the sextant (SXT), scanning telescope (SCT), or MARK button is not usable, the crew has recourse to the Backup IMU Realignment Program, P54 (paragraph 7.2.4), which operates in conjunction with the crew optical alignment sight (COAS).

7.2.2.1 Related Routines

Six routines are related to the IMU Realignment Program; five of these are called automatically by P52 at various stages of the realignment. The routines are as follows:

a. IMU Status Check Routine (R02)
b. Coarse Align Routine (R50)
c. Automatic Optics Positioning Routine (R52)
d. Sighting Mark Routine (R53) (called by R52 when crew places Optics Mode switch in MAN)
e. Sighting Data Display Routine (R54)
f. Gyro Torquing Routine (R55).

The IMU Status Check Routine (R02) (Figure 7.2.2-2) informs the crew if the IMU is powered down, or if there is no valid REFSMMAT in the CMC. The Coarse Align Routine (R50) (Figure 7.2.2-3) calculates the present CSM inertial orientation, the required IMU gimbal angles at the proposed orientation option, and proceeds to coarse align the IMU to within about one deg of the exact orientation desired, if the required gimbal angle changes are greater than one deg. The Auto Optics Positioning Routine (R52) (Figure 7.2.2-4) obtains the vector for the designated celestial body in Basic Reference Coordinates and calculates the required SXT shaft and trunnion angles to bring the body into the SXT field-of-view. It then drives the shaft and trunnion CDUs to enable the crew to see the celestial body desired. When the crew places the Optics Mode switch from CMC to MAN, R52 calls the Sighting Mark

Routine (R53) (Figure 7.2.2-5). R53 stores the ICDU angles, the OCDU angles, and the time of mark when the crew presses the MARK button on the optics control panel. The Sighting Data Display Routine (R54) (Figure 7.2.2-6) calculates the actual angle between the two celestial bodies marked, using celestial body data from one of the following: star tables from CMC storage; planet unit position vector (N88); or sun, earth, or moon position vectors from previous P52 calculations. R54 then calculates the angle between these same bodies using the sighting data supplied by R53. R54 finally calculates and displays the difference between the actual and observed angles for the crew's judgement concerning the accuracy of the sightings taken in R53. The Gyro Torquing Routine (R55) (Figure 7.2.2-7) calculates and displays, for crew approval, the gyro torquing angles required to bring the stable member into precise alignment with the stable member orientation vectors calculated by P52 for the option selected. R55 then pulses the IRIGs through the desired angles.

7.2.2.2 IMU Realignment Program Options

The first display the crew sees in P52 is a CMC request to choose one of four alignment options provided by the program (flashing VERB 04 NOUN 06): Preferred; Nominal; Landing Site; and REFSMMAT. (VERB 04 NOUN 06 does not appear during rendezvous sequence that requires plane-change pulse-torquing.) The functions of these options and the plane-change option are described here.

7.2.2.2.1 Preferred Alignment.—One of the purposes of the SPS and RCS thrust programs (P40 and P41, paragraphs 6.2.1 and 6.2.2) is to calculate and store the direction (in inertial space) along which the vehicle X-axis is to be aligned for an upcoming burn. (This preferred direction may also be uplinked via P27.) The preferred option in P52 then treats this vehicle orientation as a desired stable member orientation (i.e., as a future REFSMMAT). P52 calculates the gimbal angle changes required for normal or pulse-torque coarse alignment of the stable member to within about one deg of this desired alignment. When coarse alignment is accomplished, the preferred orientation is stored as the present REFSMMAT. SXT sightings and pulse torquing are then executed to remove any errors in the stable member's alignment to the new REFSMMAT.

When the stable member X-axis is parallel to the vehicle X-axis, it is also very nearly parallel to the SPS thrust vector. In this orientation, gyro drift effects due to thrust acceleration are minimized. In addition, spacecraft roll control becomes, essentially, control of the outer gimbal angle.

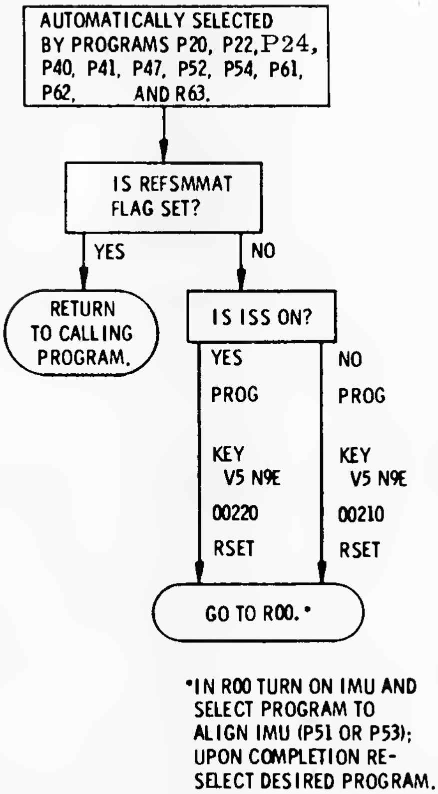


Figure 7. 2. 2-2. IMU Status Check Routine (CSM R02)

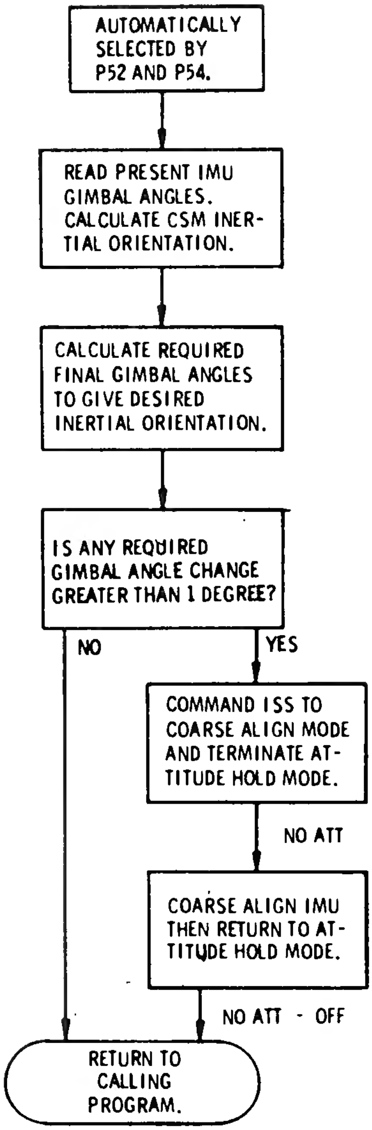


Figure 7.2.2-3. Coarse Align Routine (CSM R50)

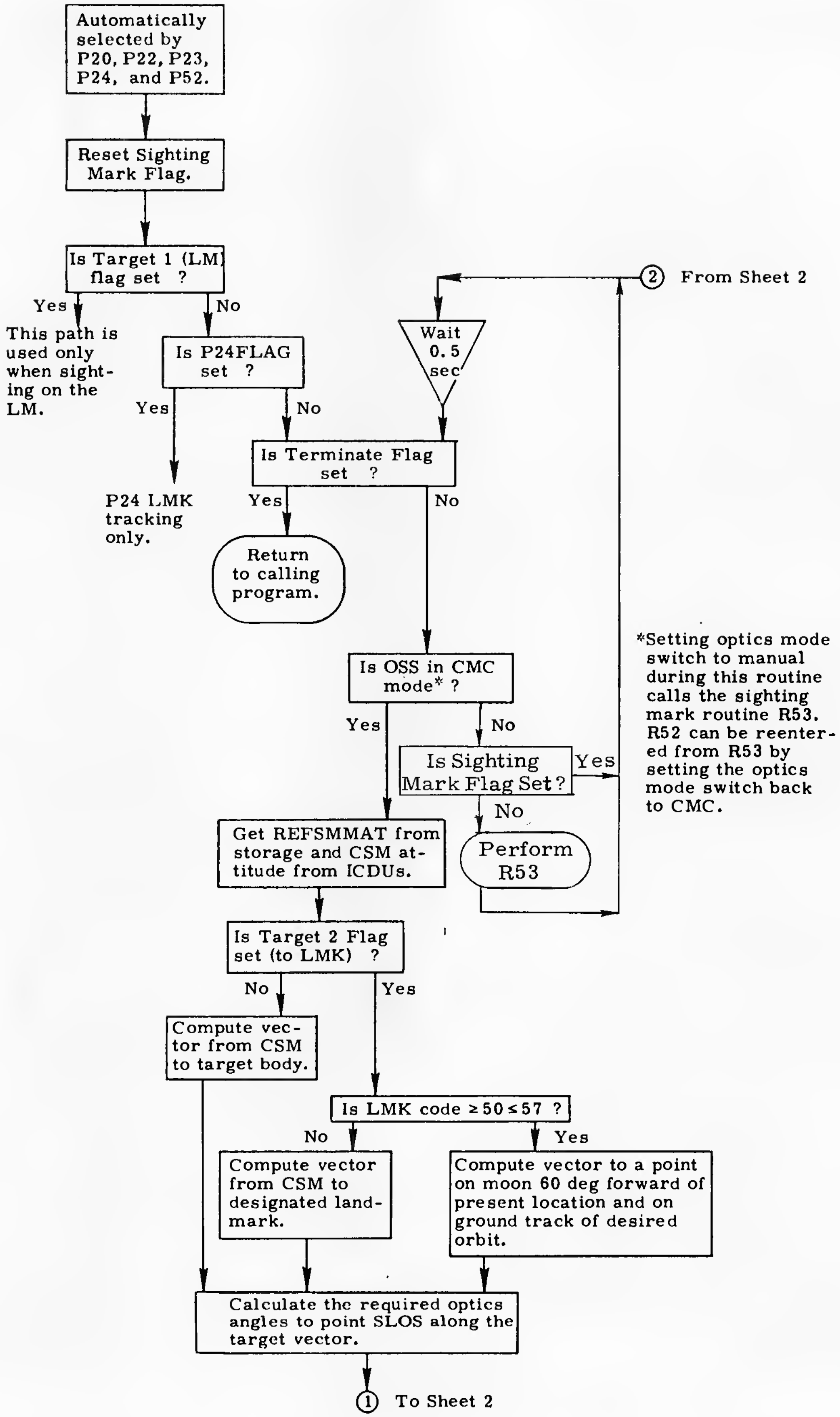


Figure 7.2.2-4. Automatic Optics Positioning Routine (CSM R52) Celestial Body (Sheet 1 of 2)

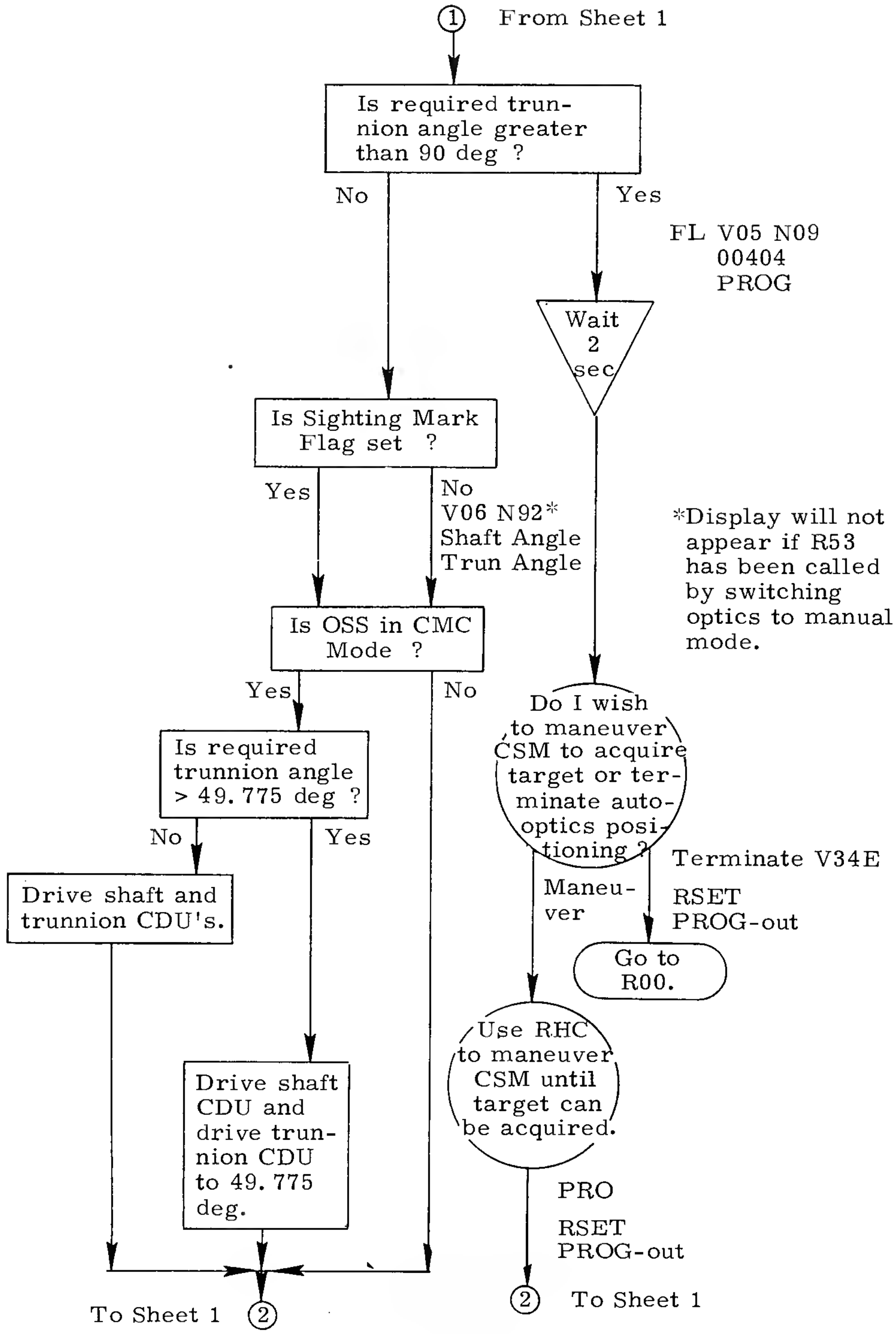
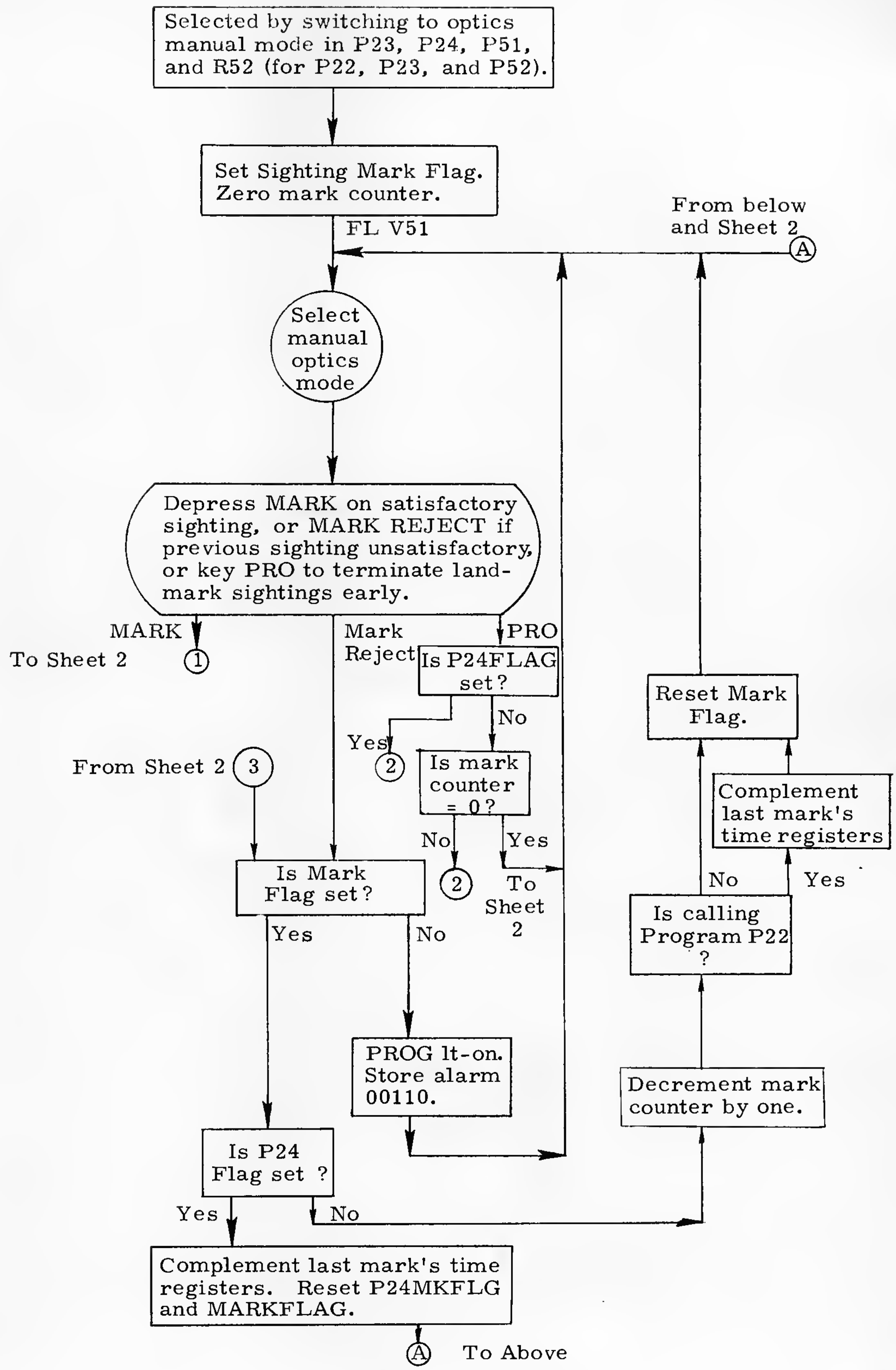


Figure 7.2.2-4. Automatic Optics Positioning Routine (CSM R52)
Celestial Body (Sheet 2 of 2)



Mark Index = 1 for Celestial Body (P23, P51, P52)
Mark Index = 5 for Landmark (P22)
Mark Index not limited for P24

Figure 7.2.2-5. Sighting Mark Routine (CSM R53) (Sheet 1 of 3)

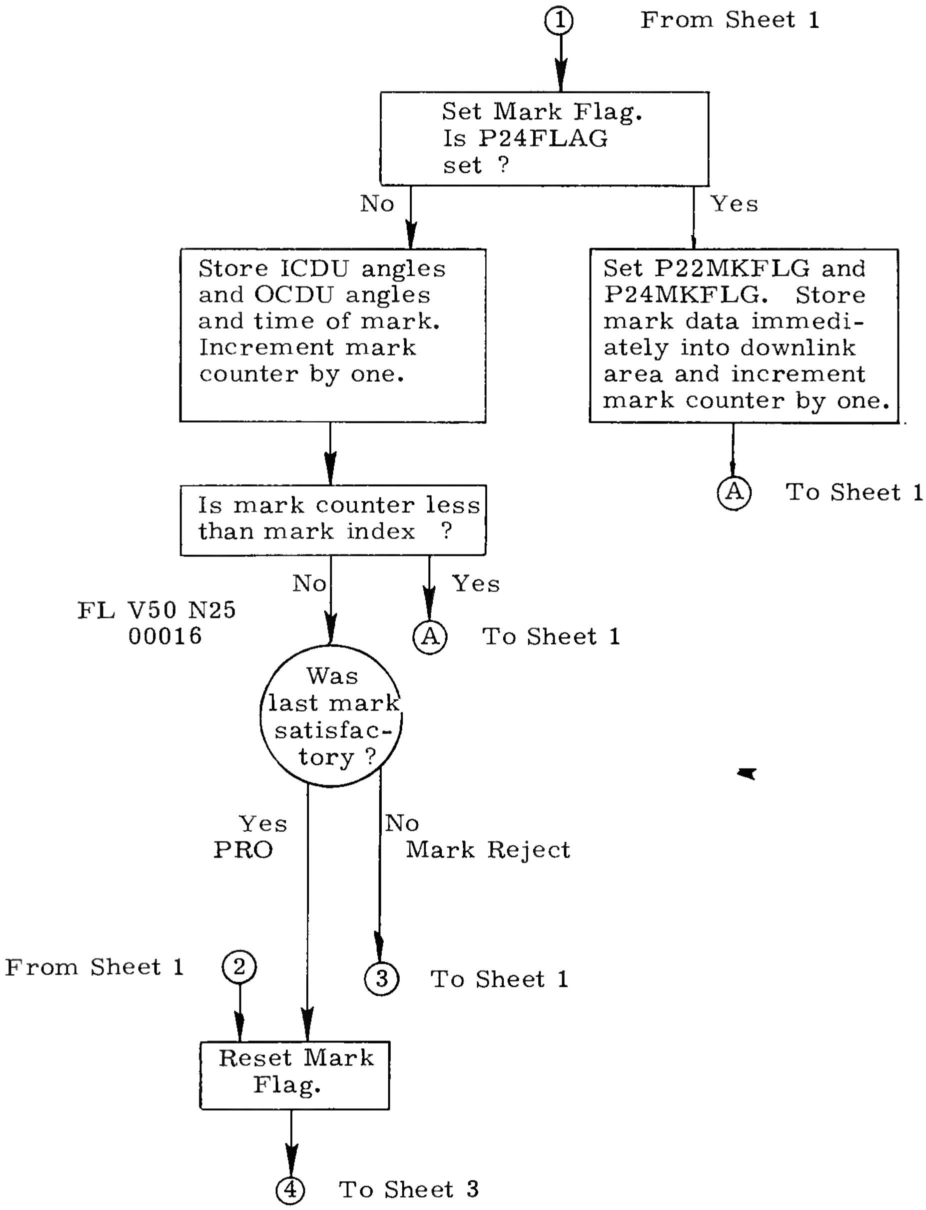


Figure 7.2.2-5. Sighting Mark Routine (CSM R53) (Sheet 2 of 3)

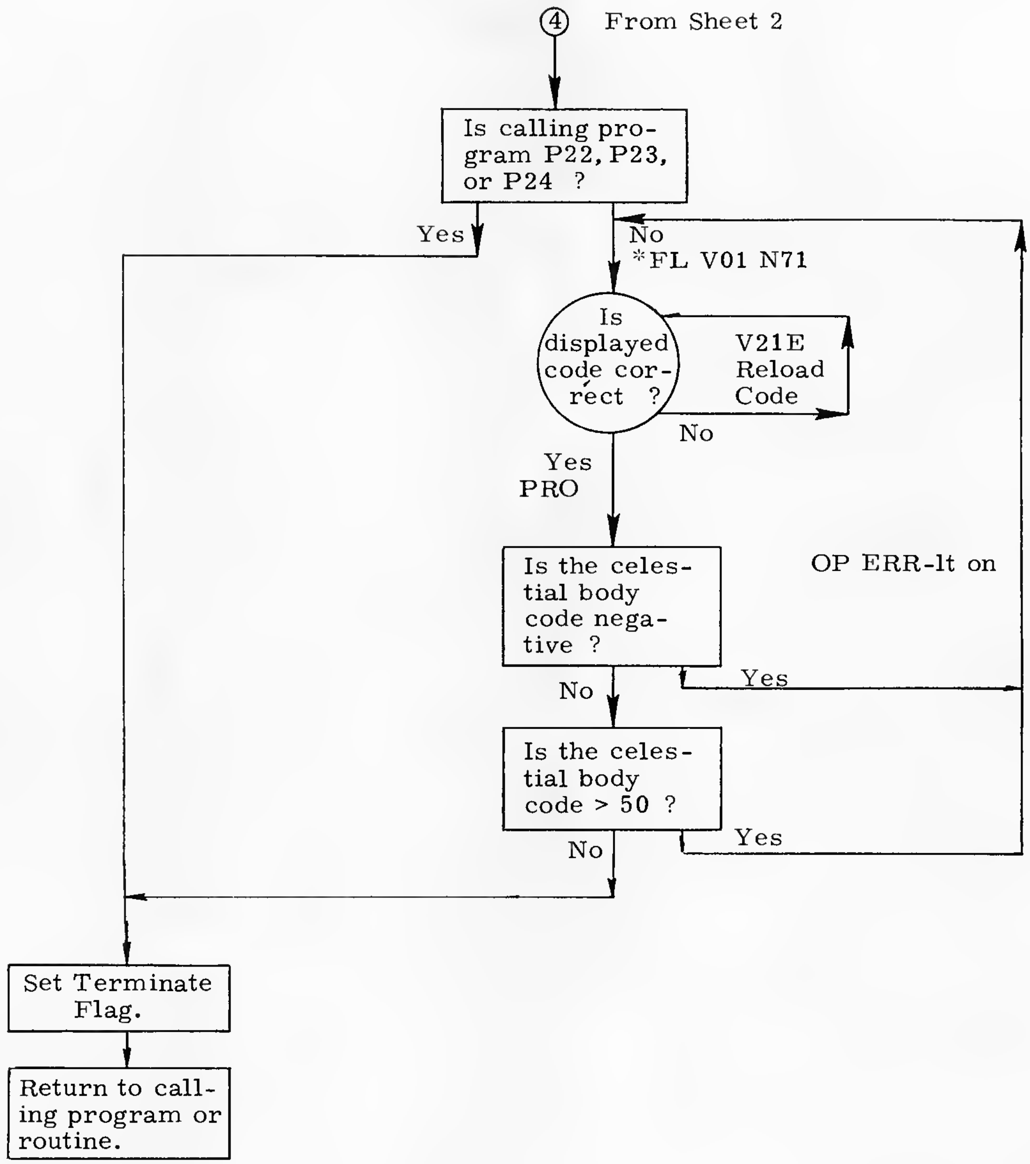


Figure 7.2.2-5. Sighting Mark Routine (CSM R53) (Sheet 3 of 3)

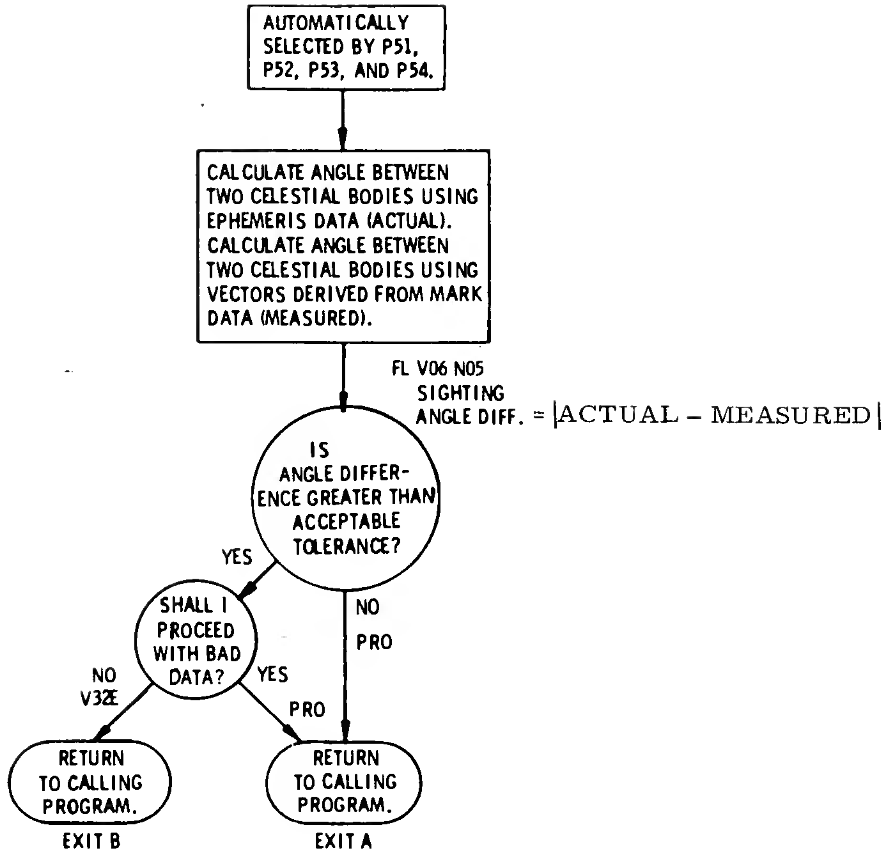


Figure 7. 2. 2-6. Sighting Data Display Routine (CSM R54)

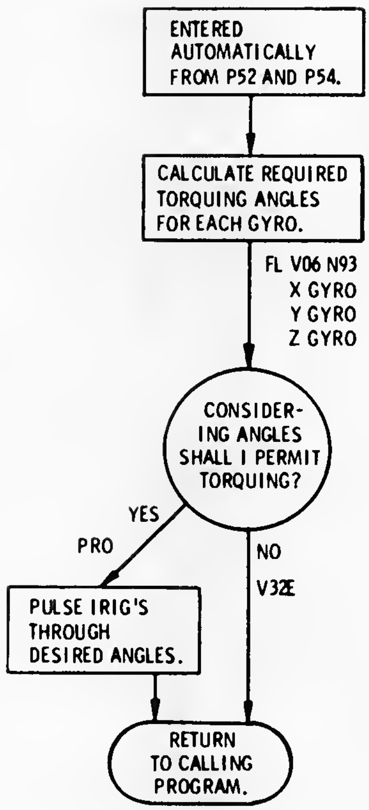


Figure 7. 2. 2-7. Gyro-torquing Routine (CSM R55)

In preferred alignment, the stable member provides the basis for a convenient FDAI display. By observing a (0,0,0) gimbal angle indication, the crew can verify that the spacecraft X-axis is in the proper orientation for the powered maneuver.

It should be noted that the orientation for a Passive Thermal Control (Barbecue) maneuver can also be uplinked and treated as a preferred orientation.

7.2.2.2.2 Nominal Alignment.—The nominal alignment option provides the spacecraft with the onboard capability to compute a stable member orientation that is independent of powered flight considerations (P40 and P41), and that is not related to the present REFSMMAT. Nominal orientation defines a heads-up, wings-level attitude for the spacecraft; it is dependent only on the CSM state vector and provides the basis for a convenient FDAI artificial horizon display while in orbit.

After the crew chooses the nominal orientation, the time of alignment is keyed in. P52 then calls a routine to integrate the vehicle's state vector up to the time specified, and then calculates the gimbal angles required to orient the stable member z-axis along the radius vector just computed, using the present vehicle attitude. The crew then proceeds with normal or pulse torque coarse alignment, then star sightings and fine alignment, to complete the program. This alignment option is less commonly used than the landing site option (paragraph 7.2.2.2.4).

7.2.2.2.3 REFSMMAT Alignment.—If three or four hours have elapsed since the stable member was realigned, normal uncompensated gyro drift will have made the stable member's actual orientation different from the stored REFSMMAT by about 0.03 deg per axis. If a critical maneuver is upcoming, the stable member orientation in the Basic Reference Coordinate System must then be realigned through SXT sightings made on stars or planets whose Basic Reference coordinates are known. P52 determines the present stable member orientation with respect to the desired stable member orientation. The program can then calculate the stable member fine alignment torquing angles required to return the stable member to the REFSMMAT orientation.

The REFSMMAT option in P52 does not call the Coarse Align Routine (R50), because R50's purpose is to realign the stable member from the present REFSMMAT orientation to a desired REFSMMAT (for examples, preferred, nominal, or landing site inertial orientation). For the REFSMMAT option, the present and desired REFSMMATS are identical.

Once the stable member's orientation error from REFSMMAT is known, the Gyro Torquing Routine, R55 (Figure 7.2.2-7), is called by P52 to perform the stable member fine alignment. In R55, the gyro stabilization loops remain closed during the pulse torquing operation, and the stable member remains inertially referenced at all times. The spacecraft is not required to maintain a constant attitude during fine alignment, and will move to follow the torqued gyros if the Digital Autopilot (DAP) is on.

7.2.2.2.4 Landing Site Alignment.—The P52 landing site option is used to align the CSM stable member X-axis parallel to the vector describing the lunar landing site in Basic Reference coordinates, at the predicted time of lunar landing or launch.

At lunar touchdown, the LM stable member must be in the landing site orientation in order to be of use to the Abort Guidance System. To facilitate LM stable member alignment after docked LM ISS power-up, the CSM and LM may be given the same REFSMMAT. To accomplish this, the CSM stable member is aligned to the landing site option. The LM IMU gimbals are then aligned to values based on the docking ring angle and the CSM gimbal angle values, giving the two vehicles the same REFSMMAT—without requiring the LM crew to use the alignment optical telescope to determine their initial stable member orientation. Paragraph 7.3.2 discusses LM IMU realignment.

If the landing site option has been selected for the CSM P52, the crew must key in the time of alignment (i.e., time of landing) and the landing site latitude, half-longitude, and altitude. The CMC then extrapolates the landing site vector's inertial orientation up to the time of alignment, and the realignment process continues through normal or pulse-torque coarse alignment, star sightings, and fine alignment.

7.2.2.2.5 Plane-change IMU Alignment.—Alignment presents no problem for a LM-active plane-change, which is performed by the LM Z-axis RCS engines (no attitude rotation). Unless the change-plane component was quite small, however, a CSM-active maneuver would require rotating the X-axis normal to the orbital plane. To avoid gimbal lock, the manual-sequencing procedure (CSM-active) is to perform an IMU Realignment (P52), by pulse-torquing to a pseudo landing site of 45-deg latitude, immediately after exiting the targeting program. After realigning the IMU, the crew calls the Powered-flight Program (P40) to perform the attitude and translation maneuver. After completing the powered-flight program, the crew manually rotates the spacecraft X-axis back into plane, then performs an IMU Realignment (P52) by pulse-torquing to the actual landing site.

7.2.2.2.6 Coarse and Fine Stable Member Positioning.—After the crew has selected an alignment option, P52 computes the gimbal angles which would be required to bring the stable member into the desired inertial orientation if the spacecraft were to maintain its present attitude. The outer, middle, and inner gimbal angles at the new stable member orientation are displayed to the crew (flashing VERB 06 NOUN 22 of Figure 7.2.2-1, sheet 2). The program then requests the crew to choose between the normal and the gyro torque methods of coarse alignment of the stable member to its new orientation (flashing VERB 50 NOUN 25, Checklist code 00013).

The term "coarse alignment" here refers to stable member repositioning without the aid of SXT sightings. Coarse alignment can be accomplished with the ISS in the coarse align mode (normal coarse alignment) or in the fine align mode (pulse torque coarse alignment). "Fine alignment" means stable member repositioning using the fine align ISS mode and orientation information derived from SXT sightings.

The normal coarse alignment option allows the stable member to be quickly aligned to a new position with a limited degree of accuracy. During the time that the stable member is being coarse aligned by the normal method, the gyro stablization loops, which keep the stable member inertially referenced, are opened. If the spacecraft attitude is changing during this alignment, the final stable member orientation will not be the actual orientation desired, since the computer cannot keep track of the inertial orientation of the spacecraft while the gyro stabilization loops are opened. The accuracy of the normal method of coarse alignment is thus dependent on the spacecraft attitude changes, if any, during coarse alignment, and, at best, is limited to about one deg. Alignment to any gimbal angle with this method takes about 15 sec. Once normal coarse alignment has taken place, the crew will have to accurately determine the new stable member orientation with respect to the desired orientation by P52's celestial body sights. The SXT can determine star directions to within about 0.01 deg; the SCT has an accuracy of about 0.05 deg.

Gyro torquing coarse alignment is an alternate astronaut response to Checklist code 00013 of flashing VERB 50 NOUN 25 above. The fine align ISS mode can be used to bring the stable member into more precise alignment with the orientation desired than is available with the coarse align ISS mode. The fine align ISS mode allows the computer to position the stable member to a predetermined gimbal angle within about 40 arc-sec. During pulse torquing, the ISS gyro stabilization loops remain closed, allowing the IMU to remain sensitive to the spacecraft inertial attitude changes at all times during the process of stable member repositioning.

The disadvantage of the fine align ISS mode is that it is slow. The larger the gimbal angle changes, the longer it takes to bring the stable member into the desired orientation (about 2 sec per deg of torquing, one axis at a time).

7.2.2.3 P52 Computational Sequence

The following paragraphs discuss the calculations and crew procedures that take place during the progress of P52 (Figure 7.2.2-1). Table 7.2.2-I lists the P52 displays.

7.2.2.3.1 Program Initiation.—The CSM crew initiates P52 by keying VERB 37 ENTR 52 ENTR into the DSKY. P52 then calls the IMU Status Check Routine, R02 (Figure 7.2.2-2), which checks to see if the REFSMMAT flag is set. If the REFSMMAT flag is cleared, R02 illuminates the PROG alarm light; this alarm is verified by keying VERB 5 NOUN 9 ENTR. The DSKY displays alarm 00210 if the IMU is not on, or 00220 if the IMU is not aligned (no REFSMMAT). P52 is then terminated automatically.

If the IMU is powered up and REFSMMAT flag set, P52 checks the status of the AUTOSEQ flag (MINKEY rendezvous sequence). AUTOSEQ is clear if astronaut started P52 via VERB 37 ENTR 52 ENTR. Processing then continues at paragraph 7.2.2.3.2 with calculation and display of gimbal angles. If AUTOSEQ is set, the plane-change stable-member orientation is computed and the PREFERRED attitude flag is set. (At this time, any previously stored preferred orientation is lost.) Processing then continues at paragraph 7.2.2.3.2 with calculation and display of gimbal angles. If AUTOSEQ is clear, P52 checks to determine if a preferred orientation has been stored (PREFERRED flag set). The first display the crew sees in P52 is a flashing VERB 04 NOUN 06, with 00001 in R1 (please specify IMU orientation option); R2 contains the orientation option code assumed by the CMC. These codes are as follows:

00001 — Preferred Alignment
00002 — Nominal Alignment
00003 — REFSMMAT Alignment
00004 — Landing Site Alignment.

R2 contains 00001 if the preferred orientation flag has been set, and 00003 if it has not. If the crew chooses an option not displayed in R2, the option code is loaded by keying in VERB 22 ENTR and the desired option code.

TABLE 7.2.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH IMU REALIGNMENT (CSM P52) (SHEET 1 OF 6)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
1	V37 ENTR 52 ENTR	Astronaut	Initiate IMU Re-align Program	---	---	---
2	FL V04 N06	P52	Request response to display of alignment option code	R1--"please specify IMU orientation" R2--option assumed by CMC; 00001 = preferred 00002 = nominal 00003 = REFSMMAT 00004 = landing site	R1 00001 checklist R2 oooox R3 Blank	Preferred-PRO to 5 Nominal-PRO to 3 REFSMMAT-PRO to 8 Landing Site-PRO to 3
3	FL V06 N34	P52	Request response to display of T_{align}	Nominal or landing site option R1, R2, R3--time of alignment in GET; all zeroes = present time	R1 00xxx. hr R2 000xx. min R3 0xx.xx sec	Load desired GET. PRO to 5 for nominal, PRO to 4 for landing site option.
4	FL V06 N89	P52	Request response to display of landing site coordinates.	Landing site option R1-- latitude (+ North) R2-- longitude/2 (+ East) R3-- altitude above mean lunar radius	R1 xx.xxx deg R2 xx.xxx deg R3 xxx.xx n.mi.	Load desired coordinates. PRO to 5.
5	FL V06 N22	P52	Request response to display of gimbal angles after proposed coarse align at present CM attitude.	All options except REFSMMAT R1-- outer gimbal R2-- inner gimbal R3-- middle gimbal	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg	If middle gimbal angle >70 deg, maneuver and V32 ENTR to 5. PRO to 6.

TABLE 7.2.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH IMU REALIGNMENT (CSM P52) (SHEET 2 OF 6)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
6	FL V50 N25	P52	Request astronaut to perform normal or pulse torque coarse align	Proposed gimbal angles satisfactory R1-- "please perform coarse align"	R1 00013 checklist R2 Blank R3 Blank	Normal coarse align—PRO, monitor NO ATT light on, then off, go to 8. Pulse torque—CMC Mode switch to FREE, ENTR to 7.
7	V16 N20	P52	Monitor gimbal angles	Pulse torque coarse align in progress R1-- outer gimbal R2-- inner gimbal R3-- middle gimbal	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg	Monitor for potential gimbal lock. Go to 18.
8	FL V50 N25	P52	Request celestial body acquisition	Normal coarse align accomplished. R1-- "please perform celestial body acquisition"	R1 00015 checklist R2 Blank R3 Blank	Maneuver if necessary. CMC star acquisition—PRO to 9. Manual acquisition-ENTR to 9.
9	FL V01 N70	P52	Display celestial body identification code	R1-- 00000=any planet 00001 to 00045 =star 00046, 47, 50 =sun, earth, moon	R1 oooxx celestial identification code R2 Blank R3 Blank	Load desired code. Optics Mode to CMC, Optics Zero to OFF, PRO to 11 (or to 10 if R1 = 00000).

TABLE 7.2.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH IMU REALIGNMENT (CSM P52) (SHEET 3 OF 6)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
10	FL V06 N88	P52	Request response to display of planet position vector	Celestial body code =00000 R1-- X-component of planet unit position vector at alignment time R2-- same as R1 for Y-component R3-- same as R1 for Z-component	R1 .xxxxx Xpl R2 .xxxxx Ypl R3 .xxxxx Zpl	Load vector and PRO to 11.
11	V06 N92	R52	Display desired optics angles	Will not appear if R53 has been called by setting Optics Mode switch to MAN R1-- shaft angle R2-- trunnion angle	R1 xxx.xx deg R2 xx.xxx deg R3 Blank	To call mark routine, set Optics Mode switch to MAN. Go to 12.
12	FL V51	R53	Request mark.	Optics Mode switch in MAN	---	Use Mark pushbutton. Go to 13.
13	FL V50 N25	R53	Request terminate marking	One mark has been taken on the target R1-- "please terminate marking"	R1 00016 checklist R2 Blank R3 Blank	To terminate marking, PRO to 14.
14	FL V01 N71	R53	Request response to display of celestial body code	Mark sequence has been terminated	R1 oooxx celestial body code R2 Blank R3 Blank	Load code if needed. PRO to 9 after first mark (to 15 if code = 00). PRO to 16 after second mark (to 15 if code = 00).

TABLE 7.2.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH IMU REALIGNMENT (CSM P52) (SHEET 4 OF 6)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
15	FL V06 N88	P52	Request response to display of celestial body vector	Celestial body code = 00000	R1 .xxxxx Xpl R2 .xxxxx Ypl R3 .xxxxx Zpl	Load vector if needed. PRO to 9 after first mark. PRO to 16 after second mark.
16	FL V06 N05	R54	Request response to display of difference between actual and measured celestial body angles	Two celestial bodies have been marked R1-- sighting angle difference	R1 xxx.xx deg R2 Blank R3 Blank	To reject—V32 ENTR to 18. To accept—PRO to 17.
17	FL V06 N93	R55	Request response to fine align torquing angles	Satisfactory sighting angle difference R1-- outer gimbal R2-- inner gimbal R3-- middle gimbal angles through which gyros must be torqued to complete fine alignment.	R1 xx.xxx deg R2 xx.xxx deg R3 xx.xxx deg	To torque-CMC Mode switch to FREE and PRO to 18. To bypass torquing-V32 ENTR to 18.
18	FL V50 N25	P52	Request third star check	R1-- "please perform third star alignment check"	R1 00014 checklist	Third star check—PRO to 8. Bypass star check and terminate P52—ENTR and set Optics Zero switch to ZERO.

TABLE 7.2.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH IMU REALIGNMENT (CSM P52) (SHEET 5 OF 6)

DSKY	Initiated By	Purpose	Condition	Register
V05 N09 ENTR	Astronaut	Verify PROG alarm	00110--MARK REJECT depressed unnecessarily 00114--too many marks taken 00115--Optics Mode switch not in CMC for auto optics positioning 00116--optics not zeroed 00117--V41 N91 cannot be executed now 00120--optics not zeroed at time of optics torque request 00121--mark taken during CDU transient or CM rotating too fast 00206--ICDU zero not allowed during gimbal lock 00207--ISS turn-on not present for 90 sec 00210--IMU not on 00211--coarse align error 00217--ISS mode switch failure 00220--no valid REFSMMAT 00401--desired angles yield gimbal lock 00402--improper response to plane-change request	R1 xxxxx R2 xxxxx R3 xxxxx

TABLE 7.2.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH IMU REALIGNMENT (CSM P52) (SHEET 6 OF 6)

DSKY	Initiated By	Purpose	Condition	Register
PROG FL V05 N09	P52	Display PROG alarm code	00405--two stars not available for auto optics positioning at present CM attitude	R1 xxxxx R2 xxxxx R3 xxxxx
PROG FL V05 N09	R52	Display PROG alarm code	00404--target not within hemisphere of optics visibility (trunnion angle > 90 deg)	R1 xxxxx R2 xxxxx R3 xxxxx

If the REFSMMAT option is chosen, a PRO response to VERB 04 NOUN 06 takes P52 into the first display in paragraph 7.2.2.3.3 below; otherwise, a PRO response under the landing site or nominal options causes a flashing VERB 06 NOUN 34, with the proposed time of alignment displayed in R1, R2, and R3. (All zeroes in the registers indicates that the time of alignment is chosen to be the present time.) The crew can now reload the time by keying VERB 25 ENTR, followed by the time desired, or can accept the time indicated, by keying PRO. VERB 06 NOUN 34 does not appear if the preferred or REFSMMAT options were chosen, since these options do not integrate any vectors ahead in time.

If the landing site option is chosen, the crew sees, after VERB 06 NOUN 34, a flashing VERB 06 NOUN 89—a request to respond to the computer's display of the lunar landing site coordinates. R1 contains the landing site latitude in degrees, to 0.001 deg (+ signifies North); R2 contains the longitude divided by two, to 0.001 deg (+ signifies East); R3 contains the landing site altitude to 0.01 n. mi. To load new coordinates, the crew keys in VERB 25 ENTR, followed by the correct coordinates. These are displayed to the crew and approved by a PRO response to flashing VERB 06 NOUN 89. At this time, any previously stored preferred orientation is lost. P52 then computes the landing site vector's orientation at the time specified, and proceeds to the gimbal angle computations discussed below in paragraph 7.2.2.3.2.

If the nominal option is chosen and the time of alignment specified, P52 calculates the CSM state vector at the time of alignment and uses it to calculate the desired stable member orientation. (VERB 06 NOUN 89 above will not appear in this program option.) Execution of the nominal option erases any previously stored preferred orientation.

7.2.2.3.2 <u>Gimbal Angle Computation.</u>—In the preferred, nominal, or landing site options, the CMC now has the desired stable member inertial orientation. Next, the CMC computes the gimbal angles required for the present CSM orientation and the proposed stable member orientation. These angles are displayed via a flashing VERB 06 NOUN 22; R1, R2, and R3 display, respectively, the outer, inner, and middle gimbal angles to the nearest 0.01 deg. If this display represents a potential gimbal lock (middle gimbal angle greater than 85 deg), the crew can reorient the spacecraft with the rotational hand controller and recycle P52 to recompute the proposed gimbal angles, by keying VERB 32 ENTR. (P52 may also be terminated at this time.) If the astronaut is not performing a plane-change realignment, a PRO response to the gimbal angles displayed produces a flashing VERB 50 NOUN 25, with R1 containing Checklist code 00013 (please perform coarse align).

At this point, the crew can perform a normal coarse alignment to the new orientation, followed by a pair of celestial body sightings to accurately determine the new alignment. Alternatively, the crew can pulse torque the gyros to the new orientation, with the ISS remaining in the fine align mode. The pulse torquing operation bypasses SXT sightings. (See paragraph 7.2.2.2.6.)

If the astronaut is performing plane-change realignment, then a PRO response to VERB 06 NOUN 22 is followed by flashing VERB 50 NOUN 25, 00020 (please perform plane-change pulse-torquing). Before the burn, the astronaut can key ENTR to terminate P52 or key PRO to pulse-torque the stable member. After the burn, the astronaut must key PRO to pulse-torque back to the original orientation. Keying ENTR after the burn here causes alarm 00402 ("Improper response to request for plane-change pulse-torquing").

Keying ENTR to flashing VERB 50 NOUN 25, 00013 or, for plane-change, keying PRO to VERB 50 NOUN 25, 00020, causes the CMC to compute the torquing angles required for the gyros to be pulse torqued to the new orientation. The CMC then resets the REFSMMAT flag and starts torquing. During this operation, the computer monitors the changing gimbal angles and displays them under VERB 16 NOUN 20. When torquing is completed the computer stores the desired stable member orientation in REFSMMAT and sets the REFSMMAT flag. P52 then proceeds to VERB 50 NOUN 25, 00014 (please perform fine align check) of paragraph 7.2.2.3.8. For plane-change alignments, P52 sets the REFSMMAT flag after torquing, resets the PREFERRED flag, clears the plane-change flag, and terminates.

A PRO response to VERB 50 NOUN 25, 00013 (please perform coarse align) above, causes P52 to call the Coarse Align Routine, R50 (Figure 7.2.2-3). This routine again calculates the desired gimbal angles (since the spacecraft's attitude might be changing), and reads the present gimbal angles. If none of the gimbals need to be driven more than one deg, coarse alignment is bypassed and control is returned to P52. If normal coarse alignment is required, the ISS is now switched by R50 to the coarse align mode and the NO ATT light is illuminated. The stable member is then repositioned.

After normal coarse alignment, P52 takes the matrix representing the desired orientation, stores it as the present REFSMMAT, and sets the REFSMMAT flag. But REFSMMAT does not represent precisely the actual new stable member orientation, since the normal coarse alignment process has only a limited degree of accuracy. A pair of celestial body sightings are now needed to eliminate any small errors in alignment.

7.2.2.3.3. Celestial Body Acquisition.—Unless the stable member has been pulse torqued and R50 was not used, all program options have arrived at a common point and now display a flashing VERB 50 NOUN 25, with R1 containing 00015 (please perform celestial body acquisitions). The astronaut must decide whether to have the CMC pick a pair of stars for sightings or to find two targets himself.*

A PRO response to VERB 50 NOUN 25 instructs the CMC to find two stars from its stored catalog that are available to the optics at the present CSM attitude, and to select these stars for use by the Auto Optics Positioning Routine, R52. If two catalog stars are not available for sightings, P52 displays program alarm 00405. To respond to this alarm, the crew can manually maneuver the CSM and recycle to VERB 50 NOUN 25, by keying VERB 32 ENTR, or acquire a celestial body manually and key PRO. If the celestial body is acquired manually, its identification code must be supplied by the astronaut after P52 flashes VERB 01 NOUN 70, as discussed below.

After flashing VERB 50 NOUN 25, P52 flashes VERB 01 NOUN 70, with a celestial body code displayed in R1. The crew can now correct the contents of R1 by keying VERB 21 ENTR followed by the desired code. If the planet code (00000) has been loaded, a PRO response to VERB 01 NOUN 70 is followed by a flashing VERB 06 NOUN 88, with R1, R2, and R3 containing, respectively, the x-, y-, and z-components of the planet unit position vector in Basic Reference coordinates. The crew can change these values by keying in VERB 25 ENTR followed by the desired vector components.

If the target is a star or planet, P52 now has its Basic Reference System coordinates in storage. Otherwise, if the celestial body code selected above indicates the sun, earth, or moon, the CMC must now calculate the Basic Reference System vector needed by the Auto Optics Positioning Routine, R52, to bring the target into the SXT star line-of-sight.

7.2.2.3.4 Auto Optics Routine.—P52 calls R52 (Figure 7.2.2-4). R52 tests the TERMINATE flag to recognize that the Sighting Mark Routine (R53) has not yet taken a mark. R52 then reads the CSM attitude from the present gimbal angles, obtains the REFSMMAT and celestial body Basic Reference coordinates from storage, and computes the Navigation Base coordinates of the celestial body. Using these computed coordinates, R52 calculates the optics shaft and trunnion angles required to point the SXT star line-of-sight toward the target.

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* The CMC searches for stars only; the crew can use stars or planets.

If the required trunnion angle is greater than 90 deg, R52 illuminates the PROG light and flashes VERB 05 NOUN 09 to accompany alarm code 00404 (target not within hemisphere of optics visibility). The crew can respond to this display by terminating P52 via VERB 34 ENTR, or by maneuvering the CSM until the target can be acquired and then recycling the optics pointing by keying PRO.

If the required trunnion angle is less than 90 deg but greater than 49.775 deg, no alarm is displayed. Instead, the trunnion will be driven to 49.775 deg in the direction of the line of sight desired, and the crew must maneuver the CSM to acquire the target.

For trunnion angles less than 90 deg, R52 displays VERB 06 NOUN 92, with R1 containing the desired shaft angle and R2 containing the desired trunnion angle. (This is an information display only; no crew response is required.) The shaft and trunnion CDUs are now driven to the angles displayed, and, when the crew places the Optics Mode switch in MAN, R52 calls the Sighting Mark Routine, R53.*

7.2.2.3.5 Sighting Mark Routine (R53).—The Sighting Mark Routine (Figure 7.2.2-5) first flashes VERB 51 (please mark on celestial body). The crew now centers the target on the SXT or SCT reticle and depresses the MARK button, instructing the CMC to record the time of mark, the gimbal angles, and the optics angles. The MARK REJECT button is used to reject the sighting, flash VERB 51, and to try again. When the mark is taken, R53 flashes VERB 50 NOUN 25, with R1 containing 00016 (please terminate mark sequence by keying PRO). A PRO response indicates to the CMC that marking is terminated on this target.

R53 now flashes VERB 01 NOUN 71, with the celestial body code stored by the CMC displayed in R1. If the astronaut marked on a different target than the one designated by P52, he has to load the correct target identification code now, by keying VERB 21 ENTR and the code. When the code value is satisfactory and the crew keys PRO, R53 sets the TERMINATE flag. For planets (identification code 00000), P52 displays flashing VERB 06 NOUN 88 with the planet vector Basic Reference components in R1, R2, and R3. These components can be corrected via VERB 25 ENTR or approved via a PRO. The CMC calculates and stores a target line-of-sight vector in present stable-member coordinates using the optics and gimbal mark data. (The Optics Mode switch should now be returned to CMC, to enable the computer to position the optics for the second celestial body to be marked.)

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*In R53, if the astronaut switches from MAN to CMC, the program remains in R53, but the optics is automatically pointed at the target.

P52 now selects the second star of the pair it obtained for auto optics positioning and recycles to the flashing VERB 01 NOUN 70 above. The procedures of crew celestial body selection, auto optics positioning (R52), sighting mark, and celestial body vector calculation (R53) are repeated for the second target.

7.2.2.3.6 Sighting Data Display Routine (R54).—After two celestial bodies have been marked, P52 calls the Sighting Data Display Routine, R54 (Figure 7.2.2-6). This routine first calculates the observed angle between the two celestial body vectors as measured in stable member coordinates. It then calculates this angle using the CMC stored Basic Reference vectors for the targets selected, and finds the difference between these two angles. This difference between the stored and measured star angles is displayed in R1 via flashing VERB 06 NOUN 05.

If this angle difference is unacceptably large, the crew can key in VERB 32 ENTR. This will return control to P52, which will flash VERB 50 NOUN 25, 00014 (please perform fine align check). The stable member will not be pulse torqued into alignment (Figure 7.2.2-1, sheet 4).

If the sighting data of VERB 06 NOUN 05 is satisfactory, the crew will instruct the CMC to torque the gyros by keying PRO. CMC control is then transferred to the Gyro Torquing Routine.

7.2.2.3.7 Gyro Torquing Routine (R55).—During this routine (Figure 7.2.2-7), the CMC reads the desired stable member orientation (now stored as REFSMMAT) and the actual stable member orientation (calculated from celestial body sights), and calculates the difference between the two. The computer then calculates the gyro torquing angles required to reduce this stable member alignment error to zero. The crew now sees a flashing VERB 06 NOUN 93, which is a display of the angles through which the stable member must be pulse torqued to complete the fine alignment to the orientation specified in REFSMMAT. The outer, inner, and middle gyro-torquing angles are displayed in registers R1, R2, and R3, respectively.

If these angles are too large (possibly from a faulty sighting) or represent a potential gimbal lock, the crew may bypass gyro-torquing. A VERB 32 ENTR here will return control to P52, which will generate flashing VERB 50 NOUN 25, 00014 (please perform fine align check). The astronaut responds by terminating P52 (ENTR) or recycling P52 to the beginning of celestial body acquisition (PRO).

If the displayed torquing angles are satisfactory, a PRO response to the VERB 06 NOUN 93 data will instruct the CMC to torque the stable member into the correct orientation.

7.2.2.3.8 Third Star Check.—When torquing is accomplished, the PREFERRED flag is reset. Any succeeding programs that test the PREFERRED flag (such as succeeding P52's) will now be informed that a preferred attitude is not stored. P52 next flashes VERB 50 NOUN 25, with R1 containing Checklist code 00014 (please perform fine align check). The astronaut can now, if desired, test the accuracy of the stable member realignment by having the computer point the optics at a star.

Keying PRO returns P52 to flashing VERB 50 NOUN 25, Checklist code 00015 (please perform celestial body acquisition). Another PRO will command the CMC to search its catalog for a usable pair of stars, as before (paragraph 7.2.2.3.3) and to flash VERB 01 NOUN 70. A third PRO will cause a star to appear in the SXT. The astronaut might want to take marks now, if he has executed pulse torque coarse alignment. He should follow the marking and fine align pulse torquing procedures detailed above (starting with paragraph 7.2.2.3.4).

An ENTR response to "please perform fine align check" terminates P52. The IMU realignment is accomplished.

7.2.2.4 Program Alarms

Viewing a PROG alarm light on the DSKY, the crew keys VERB 05 NOUN 09 ENTR to produce a display of the alarm code—if the code has not already been displayed by the CMC. After the astronaut has taken corrective action, he should depress RSET to extinguish the PROG light and alarm and continue with the program selected. The alarm codes associated with IMU and optics operation are listed below and in Table 7.2.2.-I.

a. Alarm 00110 indicates that the crew depressed the MARK REJECT button unnecessarily; no marks were taken yet. The astronaut should key RSET to extinguish the OP ERR light and continue normal operation.
b. Alarm 00114 indicates that more marks were made than desired. Key RSET and continue normal operation.
c. Alarm 00115 indicates VERB 41 NOUN 91 attempted to drive the optics while the Optics Mode switch was not in CMC. Set the Optics Mode switch to CMC, the Optics Zero switch to ZERO, and key RSET.
d. Alarm 00116 indicates the optics were switched to OFF from ZERO before the 15 sec optics zeroing time had elapsed. Set the Optics Zero switch to ZERO, key RSET, wait 15 sec and continue normal operation.
e. Alarm 00117 indicates Coarse Align OSS extended verb (VERB 41 NOUN 91) cannot be performed at this time. The CMC has reserved the OCDUs for other use. Key RSET and do not exec[illegible]B 41 NOUN 91.

f. Alarm 00120 indicates optics not zeroed at the time of an optics torque request. Set Optics Zero switch to OFF, then to ZERO. Key RSET and wait 15 sec before continuing normal operation.

g. Alarm 00121 indicates a mark was made at the time of a CDU switching transient or vehicle rotation rate too high. Key RSET and repeat mark.

h. Alarm 00206 indicates that zeroing the ICDUs by VERB 40 was attempted by the astronaut but not allowed during gimbal lock. When the IMU is in coarse align mode with gimbal lock, zero CDU encoding can only be done by first commanding coarse alignment to zero as follows: key RSET; key VERB 41 NOUN 20 ENTR and load 00000 ENTR, 00000 ENTR, 00000 ENTR; then key VERB 40 ENTR.

i. Alarm 00207 indicates ISS turn-on not present for 90 sec. Key RSET and reinitiate ISS turn-on sequence.

j. Alarm 00210 indicates IMU not operating. It should be turned on and the stable member orientation determined before entering P52.

k. Alarm 00211 indicates gimbal angles are not within two degrees of commanded position at time of coarse alignment. To determine magnitude of error, key VERB 06 NOUN 20 ENTR for display of gimbal angles. Continue the alignment and record the gyro torquing angles. Then do the fine align check (paragraph 7.2.2.3.8). If performing VERB 41 NOUN 20, terminate VERB 41 and align with an alignment program.

l. Alarm 00217 indicates ISS mode switching failure, possibly due to power failure during coarse or fine alignment. Key RSET and reinitiate current program. If alarm occurs, terminate use of ISS. This alarm usually accompanies alarm 00211 in R50.

m. Alarm 00220 indicates IMU not aligned. No REFSMMAT is stored. Key RSET and execute P51.

n. Alarm 00401 indicates desired angles yield gimbal lock. Key RSET and either select new gimbal angles or maneuver spacecraft to avoid gimbal lock.

o. Alarm 00402 indicates improper response (ENTR) to VERB 50 NOUN 25, 00020 (plane-change) display.

p. Alarm 00404, displayed automatically by R52, indicates optics cannot acquire the target selected (required trunnion angle greater than 90 deg). Perform one of the following and key RSET: (a) manually maneuver spacecraft until optics can acquire target and key PRO; or (b) key VERB 34 ENTR to terminate auto optics positioning routine.

q. Alarm 00405, displayed automatically by P52, indicates the computer was not able to find two target stars at the present spacecraft attitude. Perform one of the following: (a) maneuver spacecraft until two targets can be manually acquired, then key PRO; or (b) maneuver spacecraft until two useable stars can be automatically acquired, then key VERB 32 ENTR. Alarm 00405 is displayed when the computer has tested all possible pairs of stars in its catalog and is not able to find a pair that meets the following criteria: (a) the stars are not occulted by the sun, earth, or moon; (b) they are separated by between 76 and 30 deg; and (c) the pair is within 38 deg of the SXT shaft axis at the present spacecraft orientation.

7.2.2.5 Program Coordination and Procedures

P52 can be completed in approximately five minutes, if the operator is experienced. Additional time (about 15 min) will almost certainly be needed for the astronaut to dark-adapt sufficiently to see stars through the optics. The following activities should be carried out before P52 is initiated:

a. The IMU must be on for about 15 min to allow the IRIGs to reach stable operating conditions.
b. The OSS should be turned on for about 30 min to allow the optics to thermally stabilize.
c. The stable member orientation must be determined by P51 or P53.
d. The DAP Data Load Routine (R03, paragraph 9.2.1) should be performed.

An important application of P52 is its relation to SPS burn guidance. To align the stable member for a burn, the Preferred option of P52 is called during the execution of P40. A typical program sequence would be as follows:

a. The astronaut keys in a prethrust program (one of the P30's). This determines the time of ignition and velocity change. Refer to paragraph 5.2.6.7.
b. The astronaut keys in P40, and sees a flashing VERB 50 NOUN 18 (please perform a maneuver to the displayed gimbal angles). This is P40's calculation of the preferred spacecraft attitude based on the prethrust program's calculation of the desired velocity change. P40 is terminated at this point. Refer to Figure 6.2.1-2.

c. The astronaut keys in P52, and sees the Preferred option displayed as the CMC's assumed option. P52 now treats the preferred spacecraft attitude as a desired stable member attitude, and realigns the stable member axes to be parallel to the desired orientation of the vehicle axes. If the stable member was already at the proper orientation for thrusting, the REFSMMAT option could be used to eliminate any uncompensated platform drift that may have occurred since the last alignment.

   During the gyro pulse torquing process, the DAP will manuever the spacecraft to follow the platform as its inertial orientation changes, when the CMC Mode Switch is in HOLD. However, this procedure will bring the spacecraft into the preferred attitude only if the gimbal angles are at (0,0,0). (P40 can also carry out an auto maneuver; see paragraph 6.2.1.3.)

d. The astronaut returns to the beginning of P40 and executes the entire program.

P52 is also used to realign the stable member into an orientation favorable for out-of-plane SPS or TCS burns. This can be accomplished by using the Preferred option to realign to an uplinked orientation (or one calculated by P40) or by changing the CMC stored landing site coordinates and realigning via the Landing Site option. The landing site coordinate change provides the advantages of speed and independence of communication with the ground, although it is less often used than the Preferred option plane change. The landing site technique is as follows:

a. Initiate P52 and load the Landing Site option (00004). Specify the present time as the time of alignment and load a new landing site latitude of +35.000 deg if Δvy is positive or -35.000 if Δvy is negative. The half-longitude and altitude can remain unchanged.
b. If the desired ICDU angles displayed by P52 appear satisfactory, set the CMC Mode switch to FREE and key ENTR to start gyro torquing. When torquing is completed, key ENTR to terminate P52.
c. Execute P30.
d. Execute P40.
e. After the burn, yaw back manually to zero degree on the FDAI.
f. Initiate the Landing Site option of P52. Verify that the proposed time of alignment and landing site coordinates are equal to the values prescribed for the actual landing site.

g. If the desired ICDU angles displayed by P52 appear satisfactory, set the CMC Mode switch to FREE and key ENTR to torque the stable member back into plane. When torquing is completed, key PRO to acquire stars for alignment check or key ENTR to terminate P52.

The MINKEY procedure for avoiding plane-change gimbal lock is to perform the following sequence, incorporating a modified P52:

1. A new REFSMMAT is computed for a Z-gyro torqued 45 deg.
2. Resulting gimbal angles are computed and displayed (VERB 06 NOUN 22) for a Z-gyro torqued 45 deg. Crew keys PRO.
3. VERB 50 NOUN 25 (R1 = 00020) request crew to, "Please perform MINKEY PC pulse torquing."
4. Crew keys PRO (CMC MODE switch in FREE), and the Z-gyro is pulse-torqued 45 deg. (An ENTR response bypasses pulse torquing and calls P41, then P76, and proceeds to next reset point.)

    NOTE.—Once PRO is keyed on the VERB 50 NOUN 25 display, the plane-change sequence must not be interrupted. Sequence must be allowed to complete in order to reestablish original IMU alignment.

5. During torquing, present gimbal angles are displayed by VERB 16 NOUN 20. At completion of torquing, the display blanks and P40/P41 is called.
6. After regular P40/P41, the CMC calls P76 to update the LM state vector and then calls P20 to perform automatic maneuver to tracking attitude.

    NOTE.—Should it become necessary to manually avoid gimbal lock during the maneuver back to the tracking attitude, the program will proceed to step 7, and the crew will have no display available (NOUN 18) for viewing the desired gimbal angles. Unless the original maneuver to burn attitude attempted to go through gimbal lock, however, the return maneuver to tracking attitude is not likely to require manual intervention. Should manual maneuvering be required, the crew can fly the spacecraft back into plane (referencing the FDAI Ball), then respond to the pulse-torquing request. When pulse torquing has completed, the program will proceed to the next reset point, and, if further maneuvering is necessary, the crew will be requested (FL VERB 50 NOUN 18) to perform a maneuver to tracking attitude.

7. When tracking attitude obtains, the program returns to the P52 subroutines and completes the first three of the above steps in order to reestablish the original alignment.

8. Crew keys PRO (CMC MODE switch in FREE), and the Z-gyro is pulse-torqued to original alignment.

> NOTE.—An ENTR response here produces an Alarm 00402. Crew must perform pulse torquing.

9. During torquing, the present gimbal angles are displayed by VERB 16 NOUN 20. At completion of torquing, the display blanks, and program proceeds to next reset point.

Some noteworthy procedures within P52 are discussed below.

In the event that the computer is unable to find a pair of stars for sightings (program alarm 00405), the astronaut can attempt to locate and identify a pair of targets by himself. (The CMC searches for stars only; the astronaut can use stars or planets.) The Optics Hand Controller, Minimum Impulse Controller, or Rotational Hand Controller can be used to hunt for new targets. If no targets can be found, the spacecraft is generally rolled to a new attitude. When a useful target has been found, the astronaut should key PRO; the computer will then request the target's identification code (flashing VERB 01 NOUN 70).

Alternatively, after alarm code 00405, the spacecraft can be rolled into a new attitude; a VERB 32 ENTR will then instruct the computer to again search for a pair of stars.

Figure 7.2.2-8 shows the size of the accessible star field for a given vehicle attitude, for the undocked CSM. When the LM and CSM are docked, there is a small chance that the computer will position the optics to a star which is occulted by the LM. The effect of the docked LM on the size of the SXT and SCT fields of coverage is shown in Figure 4.2.3-3. If LM occultation occurs, the astronaut can search for other targets, using the optics hand controller (unless the RCS fuel supply permits maneuvering the vehicle to uncover the target). He would then mark on the target of opportunity, and then reload the target identification code after the computer flashes VERB 01 NOUN 71.

As an example of the celestial bodies available for sightings at a particular time during the mission of APOLLO 12, Figure 7.2.2-9 illustrates the view through the SCT during revolution 10 of the CSM lunar parking orbit. The circle represents

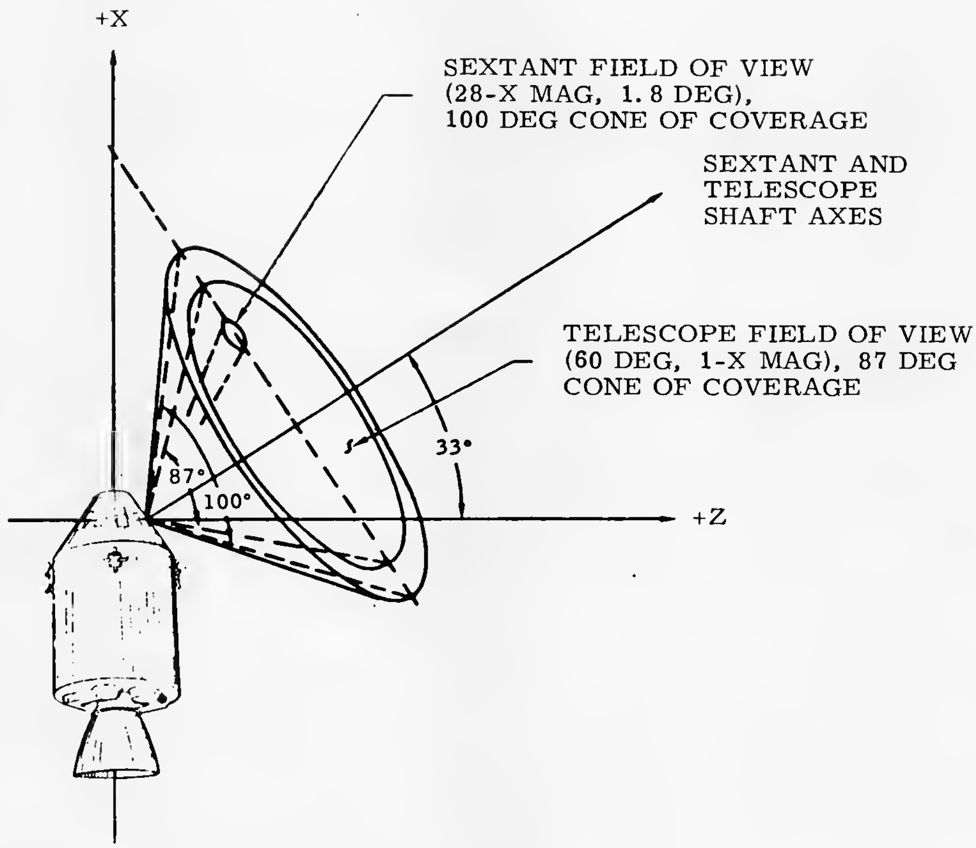
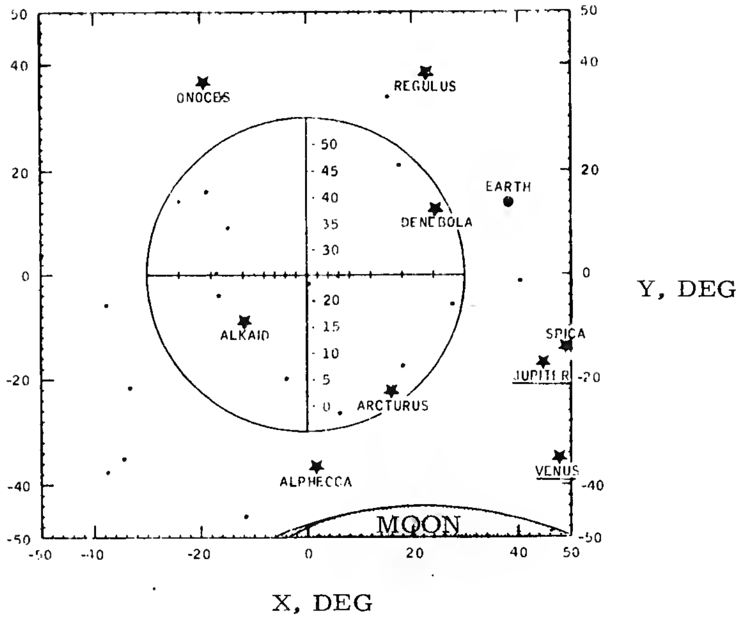


Figure 7.2.2-8. CM Optics Field of Coverage



G.E.T. = 102:50:00

Landing Site REFSMMAT

IMU Gimbal Angles:

Inner	=	330.4 deg
Middle	=	0.0 deg
Outer	=	239.9 deg

Figure 7.2.2-9. View through Scanning Telescope during Revolution 10 of APOLLO 12 Lunar Parking Orbit

the SCT field of view at zero trunnion angle—here containing three stars useful for alignment measurements. The SCT cone of coverage is large enough to allow the astronaut to also view Dnoces, Regulus, and Alphecca, without changing the CSM attitude from that described in the figure.

When the astronaut is sighting through the optics, stray light scattered from the SCT or SXT optical elements can interfere with the target. The SCT, because it has a wide field of view, is especially susceptible. The sun is the major source of unwanted light that eventually finds its way into the eyepiece; a general guideline is to keep the sun at least 60 deg from the SCT shaft axis, and at least 15 deg from the SXT lines-of-sight. The ablative cover which surrounds the optics can also be an occasional source of reflected sunlight that could obscure potential targets. With LM attached, accuracy is greatest when the shaft angle is between 100 deg and 270 deg, and the trunnion angle is less than 45 deg.

The optics CDU has an inherent limit on the SXT positioning accuracy (CDU bit size) of 40 arc-sec about the shaft axis and 10 arc-sec about the trunnion axis. The astronaut can position the SXT to greater accuracy than 40 arc-sec, however. The SCT has a star sighting accuracy of about 0.05 deg.

As discussed earlier, the Sighting Data Display Routine (R54) displays the difference between the actual and measured angles between the celestial bodies used in marking (Section 7.2.2.3.6). The crew must decide whether to accept (PRO) or reject (VERB 32 ENTR) the data. If the data are unacceptable, the celestial body marking process should be repeated.

As an example of the expected size of the star angle differences, the APOLLO 12 R54 sighting data are as follows: three displays of 0.00 deg; eight displays of 0.01 deg; three displays of 0.02 deg; and one display of 0.03 deg.

During the pulse-torquing operations in R55, VERB 16 NOUN 93 (monitor all components of delta-gyro angles) has been used to monitor the remaining angle through which the stable member is to be torqued. In this display, the amount of gyro-torquing to be completed is displayed in a separate register for each gimbal axis, with the registers initially scaled to read xx.xxx degrees. This scaling does not remain constant throughout torquing, however. As each gyro axis is torqued, the scaling of the delta-gyro angle is changed to be of use to the torquing program.

But NOUN 93 is displayed as if the scaling were unchanged. Approximately each 2.5 sec, the angle in the axis being torqued appears to have been decremented by

0.022 deg; actually, it has been decremented approximately 1.4 deg (approximately 0.55 deg/sec). Consequently, during pulse-torquing, NOUN 93 will initially display correct numbers in R1, R2, and R3. But after they start to decrease, they become more and more in error from the actual angles remaining to be torqued. The gyros are torqued in Y,Z,X order; the R2 number will diminish to a fractional degree number and then decrement to zero, while R1 and R3 remain unchanged. Then R3 undergoes the same change, and finally R1.

NOUN 20, which monitors the present gimbal angles, is suggested as a less misleading display during pulse torquing.

P52 can be used to carry out a gyro drift test. Drift can be determined from the gyro torquing angles. The test is most precise if the stable member is allowed to drift for several hours; attitude changes during the test do not affect the results. The procedure is as follows:

a. Perform P52.
b. During Gyro Torquing Routine R55, record the gyro-torquing angles (flashing VERB 06 NOUN 93) and the time, and command gyro-torquing (PRO).
c. After two hours, repeat steps a and b.
d. The second set of recorded torquing angles represents the torquing angles about the stable member axes required to correct the misalignment. The following equations relate drift to torquing angles: for the X and Y gyros,

   NOUN 93 = (-GD+LC) (0.015t); for the Z gyro,
   NOUN 93 = (+GD-LC) (0.015t).

NOUN 93 is the gyro torquing angle in deg, GD is the existing gyro drift about the gyro input axis before compensation in meru, LC is the loaded compensation in meru, t is the time in hours since the last realignment and 0.015 is the conversion factor between meru and deg/hour.

To set or clear (reset) the REFSMMAT flag, the following procedure is executed:

a. Key VERB 25 NOUN 07 ENTR. This prepares the computer to accept the REFSMMAT flag word address.
b. The CMC flashes VERB 21 NOUN 07 (please load flag word address into R1). The astronaut now keys 77 ENTR.

c. The CMC flashes VERB 22 NOUN 07 (please load code for flag bit to be changed). The astronaut keys 10 000 ENTR corresponding to bit 13 of flagword 3.

d. The CMC flashes VERB 23 NOUN 07 please set or reset (clear) the flag bit to be changed . To set the bit, the astronaut keys 1 ENTR; to clear the bit, he keys 0 ENTR.

To verify that the REFSMMAT flag is set or reset the astronaut should key VERB 01 NOUN 01 ENTR 77 ENTR. The CMC will then display VERB 01 NOUN 01, with R1 containing the flag word (ABCDE) and R3 containing the flag word address (77). Digit A in R1 will be odd if the REFSMMAT flag is set; if the REFSMMAT flag is reset, A will be even.

The automatic optics positioning capability of P52 is used to calibrate the Crew Optical Alignment Sight (COAS) by the following procedure:

a. Set the SC Cont switch to SCS, the Optics Mode Switch to CMC, and the Optics Zero switch to ZERO.

b. Key VERB 37 ENTR 52 ENTR, and when the CMC flashes VERB 04 NOUN 06 ("please select alignment option"), select the REFSMMAT alignment option.

c. When the CMC flashes VERB 50 NOUN 25 checklist code 00015 ("please perform celestial body acquisition"), key ENTR. This indicates to the computer that the astronaut will acquire a star himself.

d. The CMC will now flash VERB 01 NOUN 70. The astronaut must now load into DSKY register R1 the identification code for the star which he has chosen to center in the COAS reticle. The Optics Zero switch should now be turned off.

e. Key PRO. This instructs the computer to point the optics at the chosen star.

f. The DSKY displays VERB 06 NOUN 92 (display new OCDU angles). Center the star in the COAS by maneuvering the spacecraft. When the star is centered, hit the VERB key to freeze the displayed OCDU angles. To again monitor the new OCDU angles for another mark, hit KEY RLSE. When marking is completed and shaft and trunnion angles recorded, set the Optics Zero switch to ZERO and select another program.

This procedure determines the shaft and trunnion angles which would be required to orient the SXT line of sight parallel to the COAS line of sight. When the backup alignment programs (P53 and P54) are used, the astronaut must supply these angles to the computer.

7.2.2.6 Restarts

P52 is restart protected. Should a hardware or software restart occur, the program will, in general, return to the flashing display preceding the point of restart. If a restart occurs during pulse torquing, the stable member will be left at an unknown orientation, and the REFSMMAT flag will be left reset. It will then be necessary to execute P51 to redetermine the stable member inertial orientation.

7.2.2.7 Extended Verbs

The extended verbs discussed here are not automatically called by P52, nor are they initiated by the CSM crew as a part of the IMU Realign Program. They are separate, individual routines, designed to accomplish relatively simple tasks, i.e., to control the alignment of the stable member and optics. Table 7.2.2-II lists the extended verbs' DSKY activity.

The coarse align ISS extended verb (VERB 41 NOUN 20) is used to coarse align the gimbal angles to values specified by the astronaut (Figure 7.2.2-10). This verb is not called by P52 but can be used to align the gimbals to zero (or any other value) when the ISS is in the coarse align mode with a gimbal lock. The astronaut calls VERB 41 NOUN 20, loads the angles desired, and the computer coarse aligns the stable member. The specified gimbal angles may be displayed by keying VERB 16 NOUN 22 ENTR; the current gimbal angles may be monitored by keying VERB 16 NOUN 20 ENTR. The NO ATT light remains illuminated after VERB 41 NOUN 20 is completed. This extended verb should never be used during a process which requires the stable member to be at a constant inertial orientation, because inertial reference is not maintained during coarse alignment or after VERB 41 NOUN 20 is completed.

The coarse align OSS extended verb (VERB 41 NOUN 91) is used to drive the optics to a position selected by the operator (Figure 7.2.2-11). The OSS must be on and in the CMC mode. The astronaut loads the desired shaft and trunnion angles, and the optics are driven to the position specified by the values loaded.

The fine align extended verb (VERB 42) (Figure 7.2.2-12) is used to fine-align the stable member and to switch from coarse align to fine align mode after the coarse align extended verb is used. The operator, after observing a flashing VERB 21 NOUN 93, loads the angles through which the gyros are to be torqued. In flight, all angles must be less than 100 deg.

Note that the coarse and fine align ISS extended verbs provide neither a means of determining the stable member's inertial orientation, nor a means of alignment to one of P52's options.

The Zero ICDU extended verb (VERB 40) is used to synchronize the ISS CDU counters and the CDU counters in the CMC (Figure 7.2.2-13). VERB 40 turns off the NO ATT light and switches the ISS to fine-align mode. This extended verb cannot be used during gimbal lock. (See VERB 41 NOUN 20.)

TABLE 7.2.2-II

EXTENDED VERBS ASSOCIATED WITH CSM IMU AND OPTICS REALIGNMENT (CSM P52)

VERB	Identification	Purpose	Remarks
V41 N20	Coarse align ISS extended verb	Coarse align stable member to gimbal angles specified by astronaut	Astronaut keys in V41 N20 ENTR to initiate coarse alignment. CMC then flashes V21 N22 requesting astronaut to load gimbal angles desired. Astronaut loads outer, inner, and middle gimbal angles in DSKY registers R1, R2, and R3, respectively. CMC then displays V41 while stable member is reoriented. The NO ATT light remains illuminated during coarse alignment and after the coarse align ISS extended verb has terminated.
V42	Fine align ISS extended verb	Pulse torque stable member through angles indicated by astronaut	Astronaut keys in V42 ENTR. CMC then flashes V21 N93 requesting astronaut to load delta gyro angles. Astronaut then loads outer, inner, and middle gimbal delta gyro angles into registers R1, R2, and R3, respectively. CMC then displays V42 while pulse torquing is in progress, and the NO ATT light is extinguished.
V41 N91	Coarse align OSS extended verb	Align optics shaft and trunnion to angles specified by astronaut.	Astronaut keys in V41 N91 ENTR. CMC then flashes V21 N92 requesting astronaut to load the desired shaft and trunnion angles into registers R1 and R2, respectively. Astronaut then loads shaft and trunnion angles or keys VERB 33 ENTR to bypass loading. While the optics are being driven, the CMC displays V41.
V40	Zero ICDU extended verb.	Ensure synchronization between ISS CDU counters and CDU counters in CMC. Terminates IMU coarse align mode and enters IMU fine align mode.	Astronaut keys in V40 ENTR. CMC enters CDU Zero Mode, turns off NO ATT light, clears ISS CDU read counters, and enters ISS fine align mode.

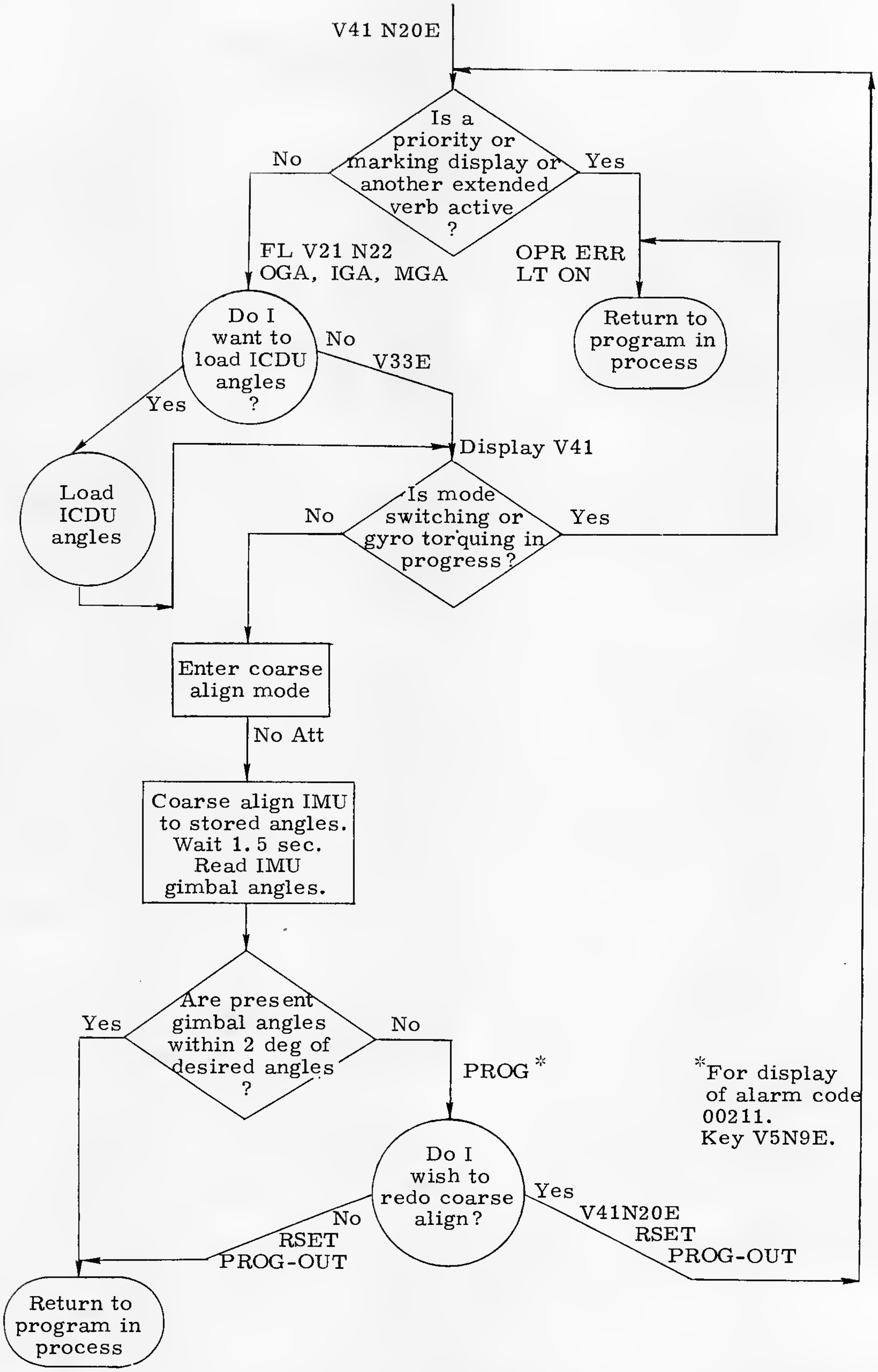


Figure 7.2.2-10. Coarse-align ISS (CSM Extended Verb V41 N20)

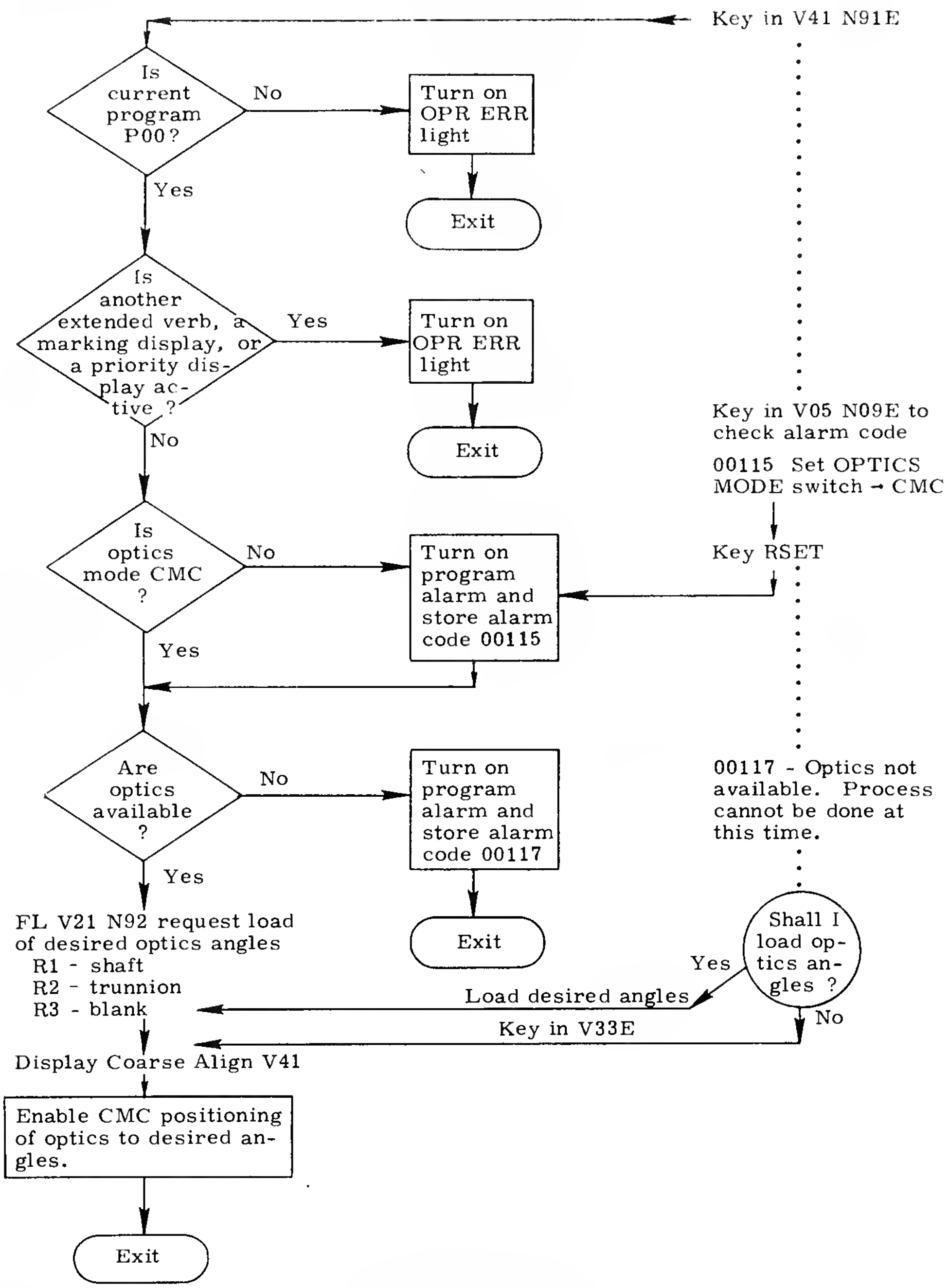


Figure 7.2.2-11. Coarse-align OCDU (CSM Extended Verb V41 N91)

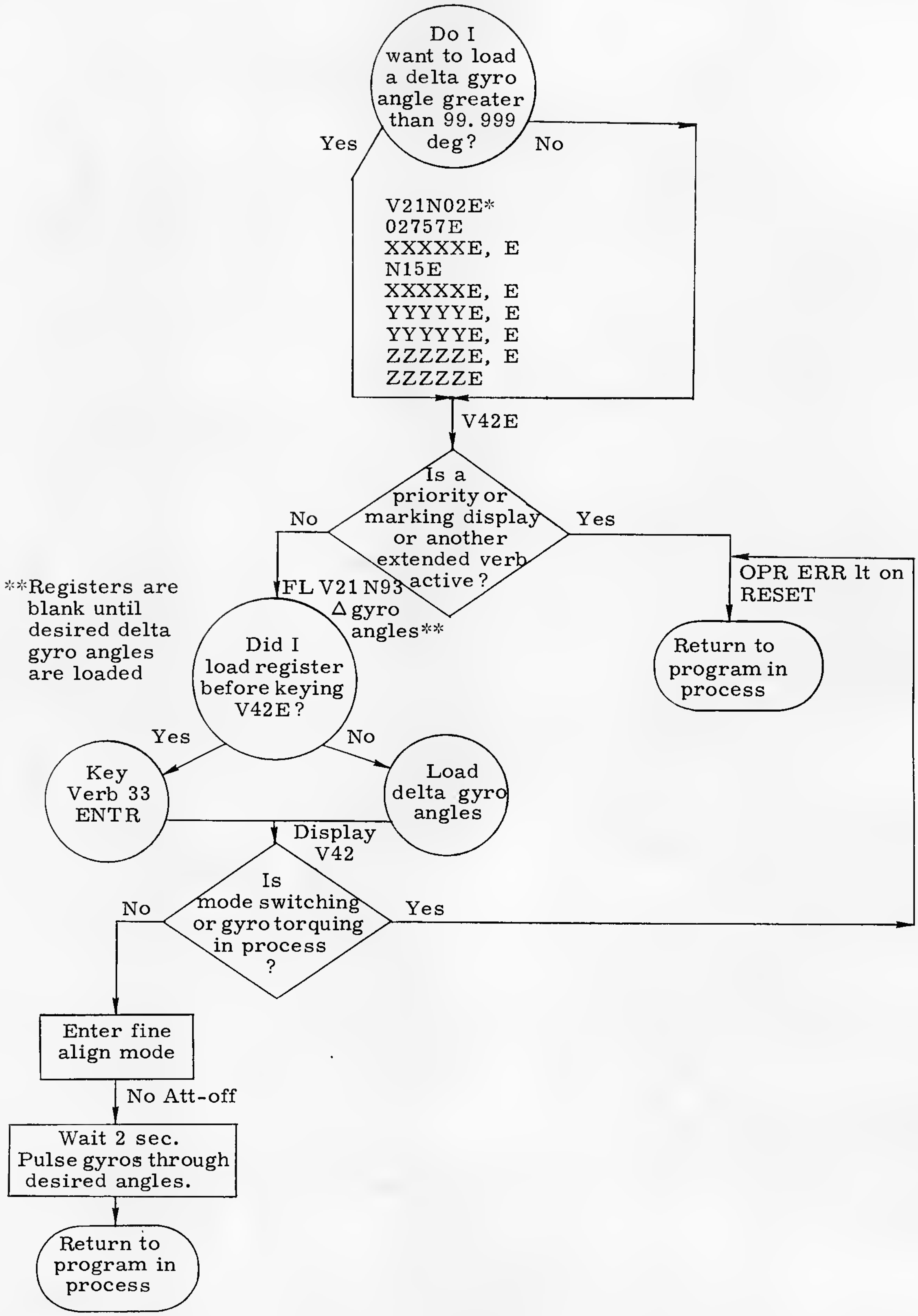


Figure 7.2.2-12. Fine-align ISS (CSM Extended Verb V42)

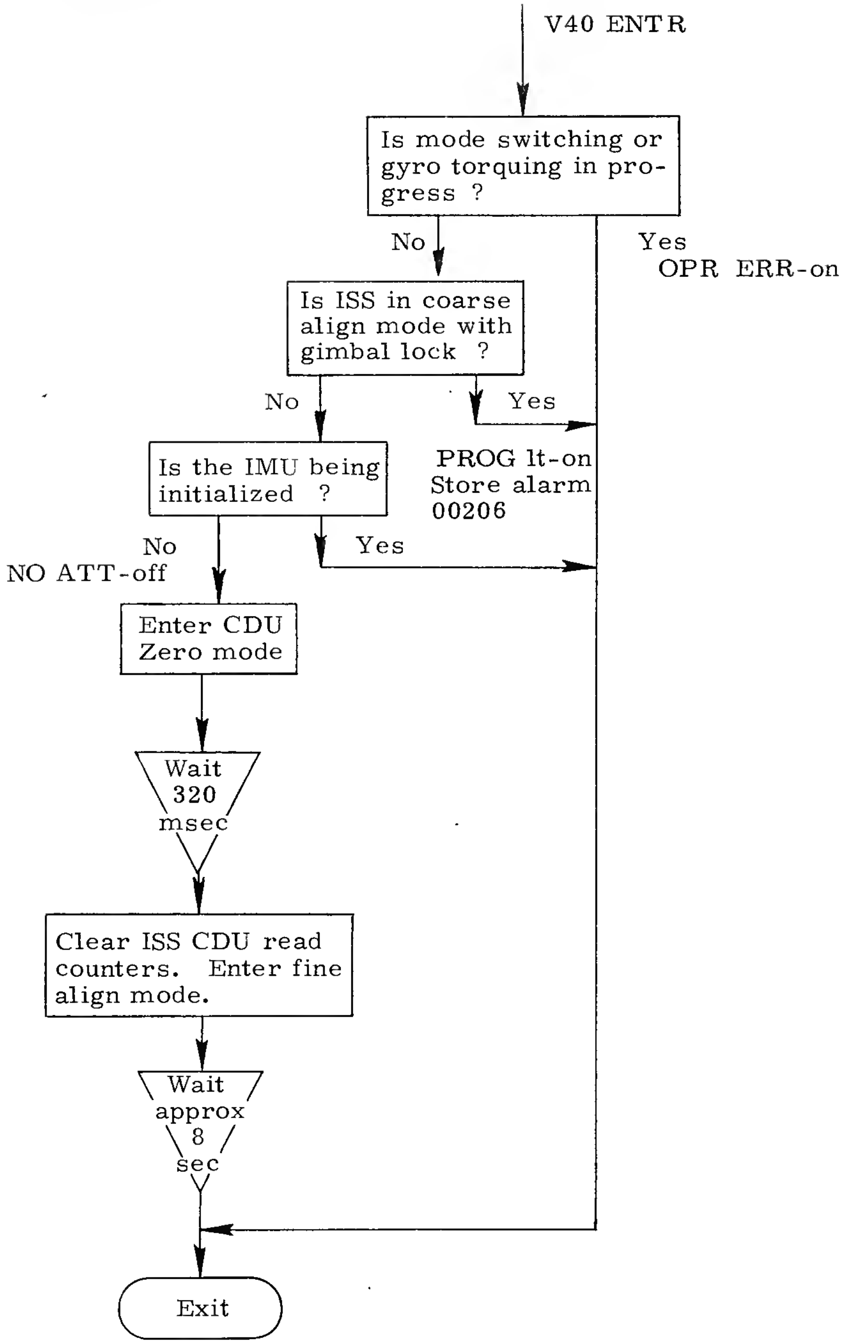


Figure 7.2.2-13. Zero ICDU Extended Verb (CSM Extended V40)

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7.2.3 P53, Backup IMU Orientation Determination—CMC

The Backup IMU Orientation Determination Program (P53) determines the inertial orientation of the ISS stable member by using a backup sighting device such as the crew optical alignment sight (COAS). P53 performs the same function as the IMU Orientation Determination Program (P51), except that P53 can be used in the event of MARK pushbutton or optics failure.

The COAS (Figure 7.2.3-1) is a collimator device similar to an aircraft gunsight. It provides a reticle image that, when viewed through one of the rendezvous windows, is used primarily to sight on the LM docking target during the docking maneuver. The astronaut performs target acquisition by maneuvering the CSM (in minimum impulse mode) until the reticle image appears to be centered on the target.

7.2.3.1 P53 Computational Sequence

P53's display sequence is identical to that of P51. The Alternate LOS sighting Mark Routine (R56) is substituted for R53. R56 accepts sighting marks and performs celestial-body vector calculations. R56 also requests the astronaut to load the SXT shaft and trunnion angles that would be required to place the SXT LOS along the COAS LOS. This information allows the CMC to calculate the LOS to the COAS target as if the SXT had actually been used for marking.* Refer to paragraph 7.2.1.3 for P51's description and Table 7.2.3-I for the displays encountered in P53.

When P53 calls R56 (Figures 7.2.3-2 and -3), the astronaut sees flashing VERB 06 NOUN 94, requesting the astronaut to approve or reload the backup optics' equivalent shaft and trunnion angles via VERB 24 ENTR. These angles are approximately 0 degrees and 57 degrees, respectively. When the astronaut is satisfied with these angles, he keys PRO and sees flashing VERB 53 ("Please perform alternate LOS sighting mark"). The astronaut positions the CSM so that the target is centered in the COAS reticle image and keys ENTR. This DSKY entry commands the CMC to store the gimbal angles, backup-optics angles, and time of mark. The remainder of the logic flow is identical to the logic flow of R53, starting with the VERB 50 NOUN 25, 00016 display ("Please terminate marking") of paragraph 7.2.1.3.

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*The shaft and trunnion angles loaded here are determined during the COAS calibration procedure discussed in paragraph 7.2.3.4.

7.2.3.2 Program Alarms

The program alarms for P53 are identical to those for P51 (paragraph 7.2.1.4), except that the following alarms are not associated with backup-optics sightings and are not generated by P53: 00110, 00114, and 00121.

7.2.3.3 Restrictions and Limitations

The restrictions and limitations associated with P51 (paragraph 7.2.1.5) apply also to P53. The use of the COAS instead of the SXT for celestial-body sightings degrades the alignment accuracy by approximately an order of magnitude. This is roughly the same accuracy as would be encountered if the scanning telescope were used for sightings.

7.2.3.4 Program Coordination and Procedures

P53 is designed to be operated by one astronaut, from either the right or left couch position. The ENTR key on the main display panel DSKY takes over the function of the MARK pushbutton during the sighting process so that the astronaut can view through one of the rendezvous windows to perform marking. The COAS LOS determination procedure uses P52 to measure the equivalent shaft and trunnion angles used with P53 and P54. This procedure is described below and should be performed some time before P53 is executed:

a. Set the OPTICS ZERO switch to OFF, then to ZERO (for a minimum of 15 sec), and key VERB 37 ENTR 52 ENTR.

b. P52 flashes VERB 04 NOUN 06. Load the REFSMMAT orientation option code (VERB 22 ENTR, 3 ENTR) and key PRO.

c. The DSKY flashes VERB 50 NOUN 25, checklist code 00015 ("Please perform celestial body acquisition"). Key ENTR to indicate manual star acquisition.

d. The DSKY flashes VERB 01 NOUN 70. Load the identification code for the star selected for COAS calibration, set the OPTICS ZERO switch to OFF, and set the OPTICS MODE switch to CMC. Key PRO.

e. The DSKY displays VERB 06 NOUN 92 with the shaft and trunnion angles that are required to point the SXT at the target celestial body. Center the target in the COAS reticle image, and mark with the VERB key. This freezes the optics angle display at the instant of marking. Record the shaft and trunnion angles for use with the backup IMU programs.

To repeat the sightings, press KEY RLSE and try again. When marking is completed, set the OPTICS ZERO switch to ZERO and select another program.

7.2.3.5 Restarts

P53 is restart protected.

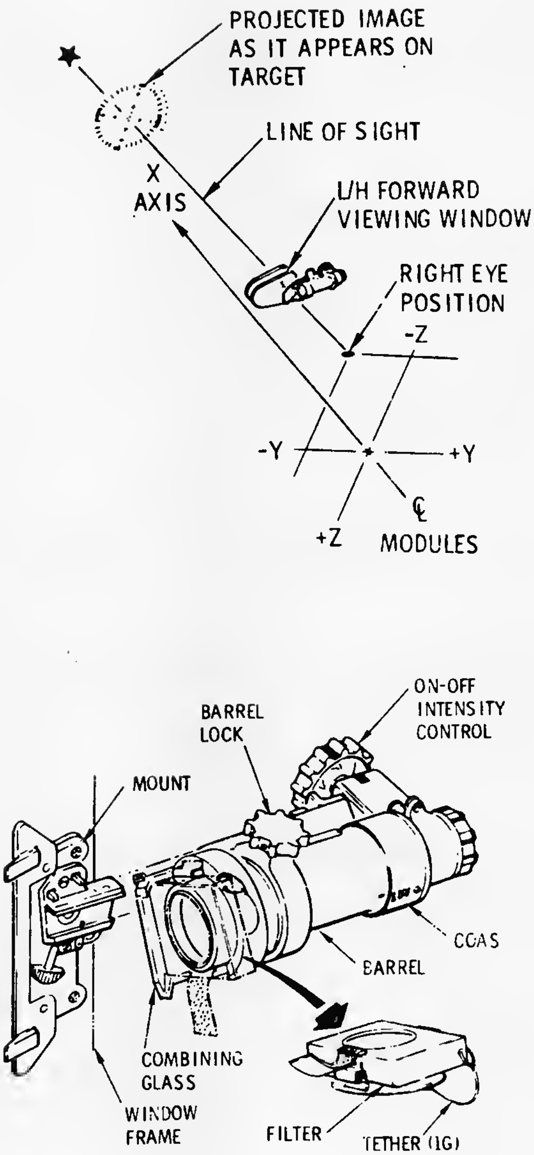

Figure 7.2.3-1. Crew Optical Alignment Sight

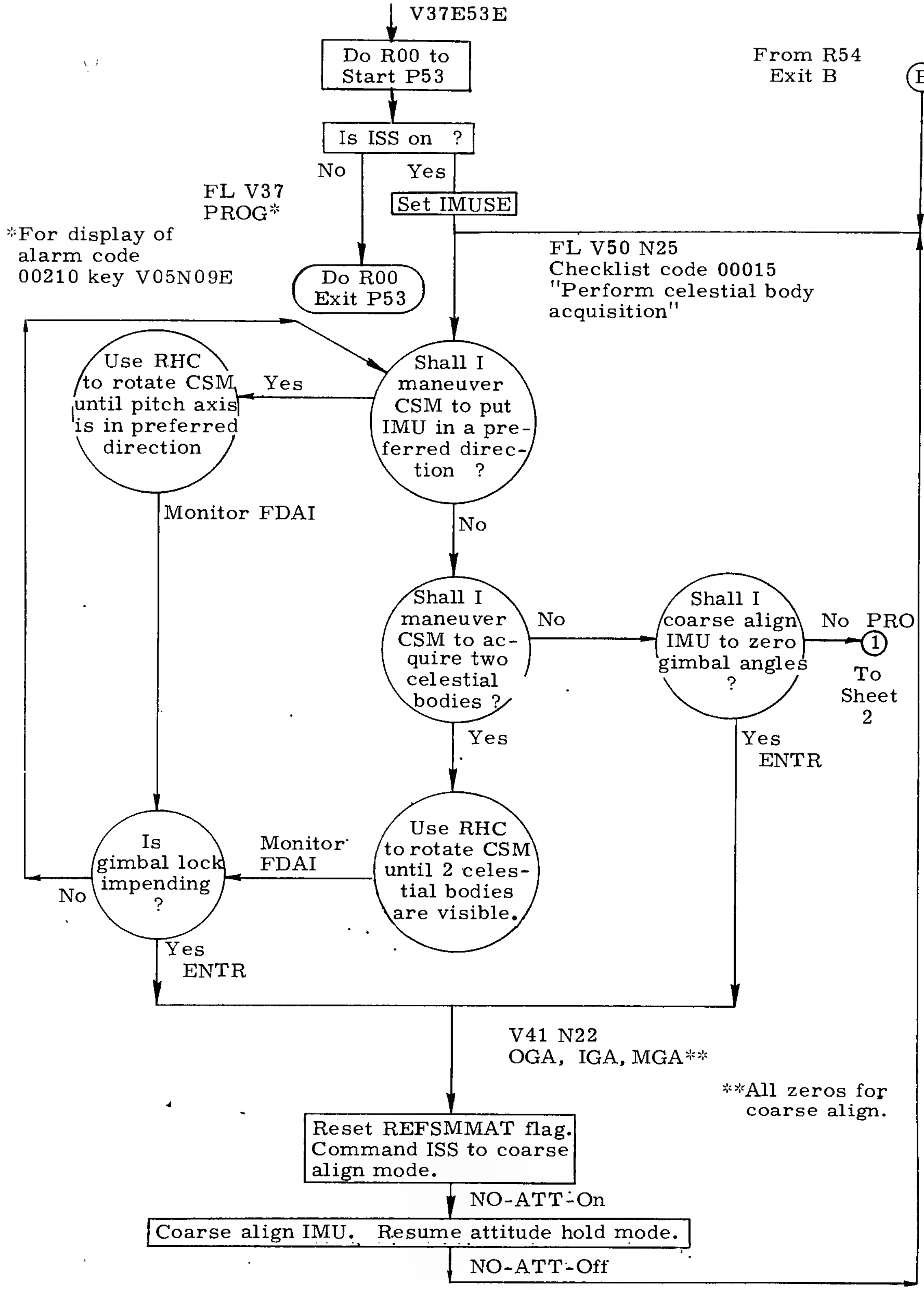

Figure 7.2.3-2. Backup IMU Orientation Determination Program (CSM P53) (Sheet 1 of 2)

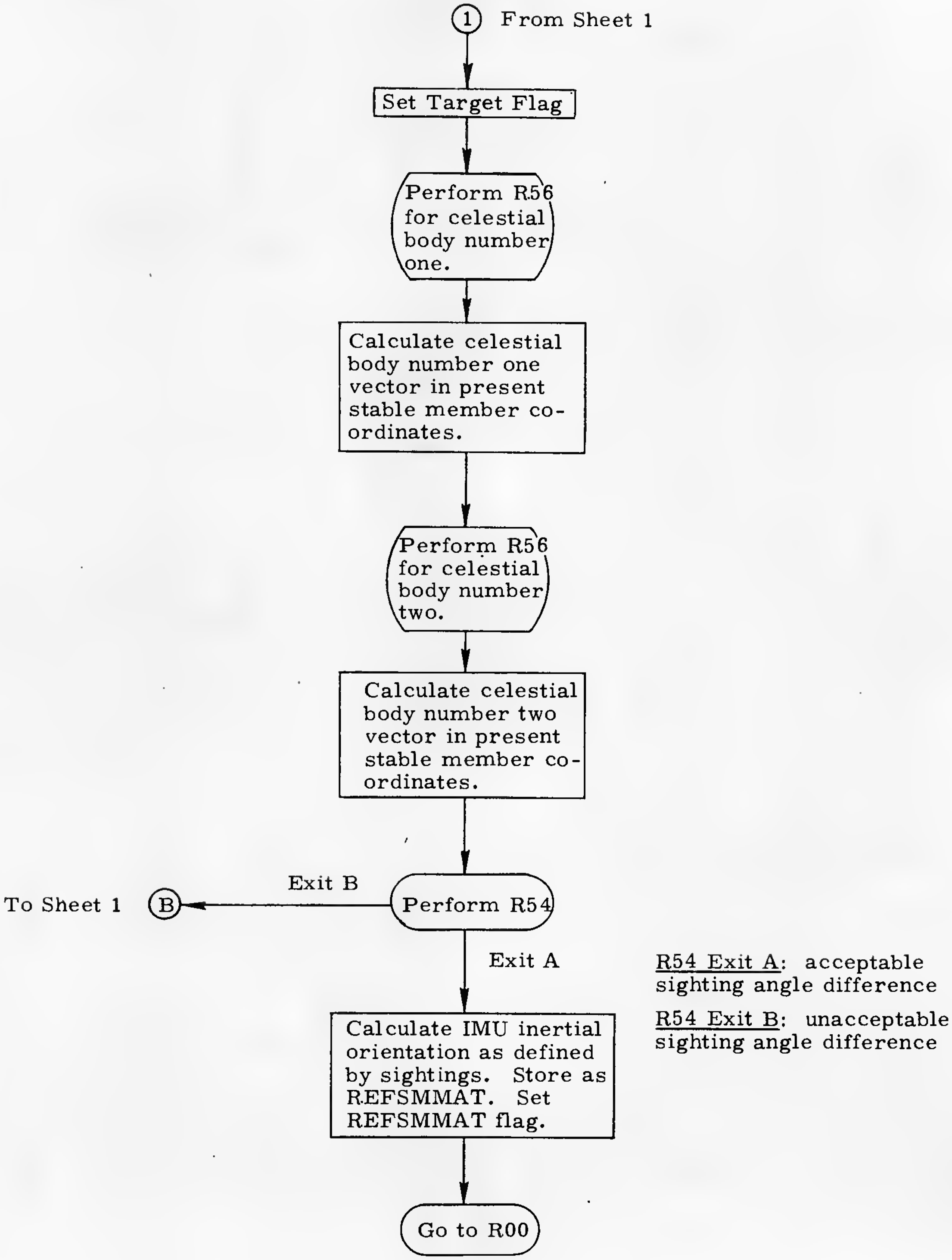

Figure 7.2.3-2. Backup IMU Orientation Determination Program (CSM P53) (Sheet 2 of 2)

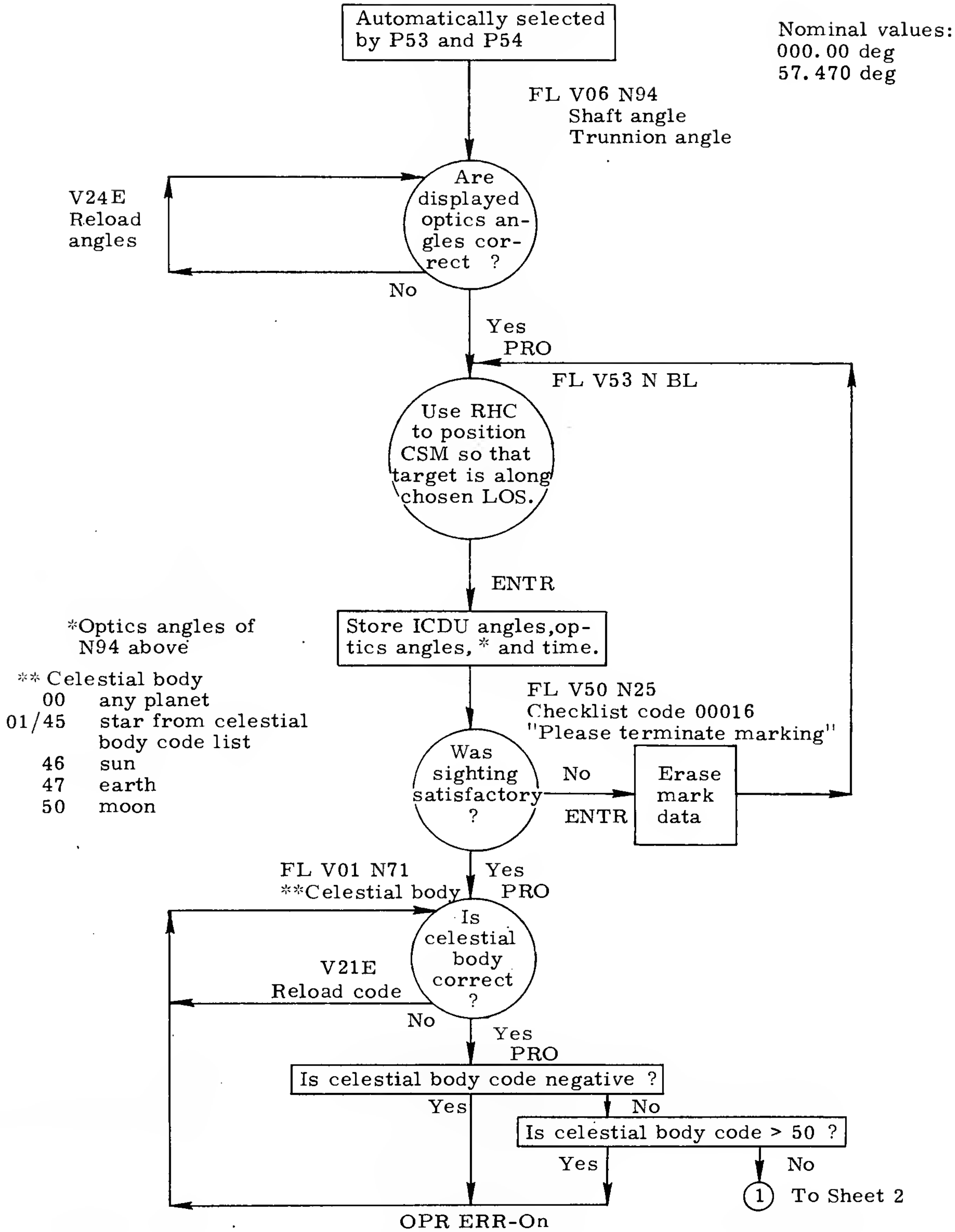

Figure 7.2.3-3. Alternate LOS Sighting Mark Routine (CSM R56) (Sheet 1 of 2)

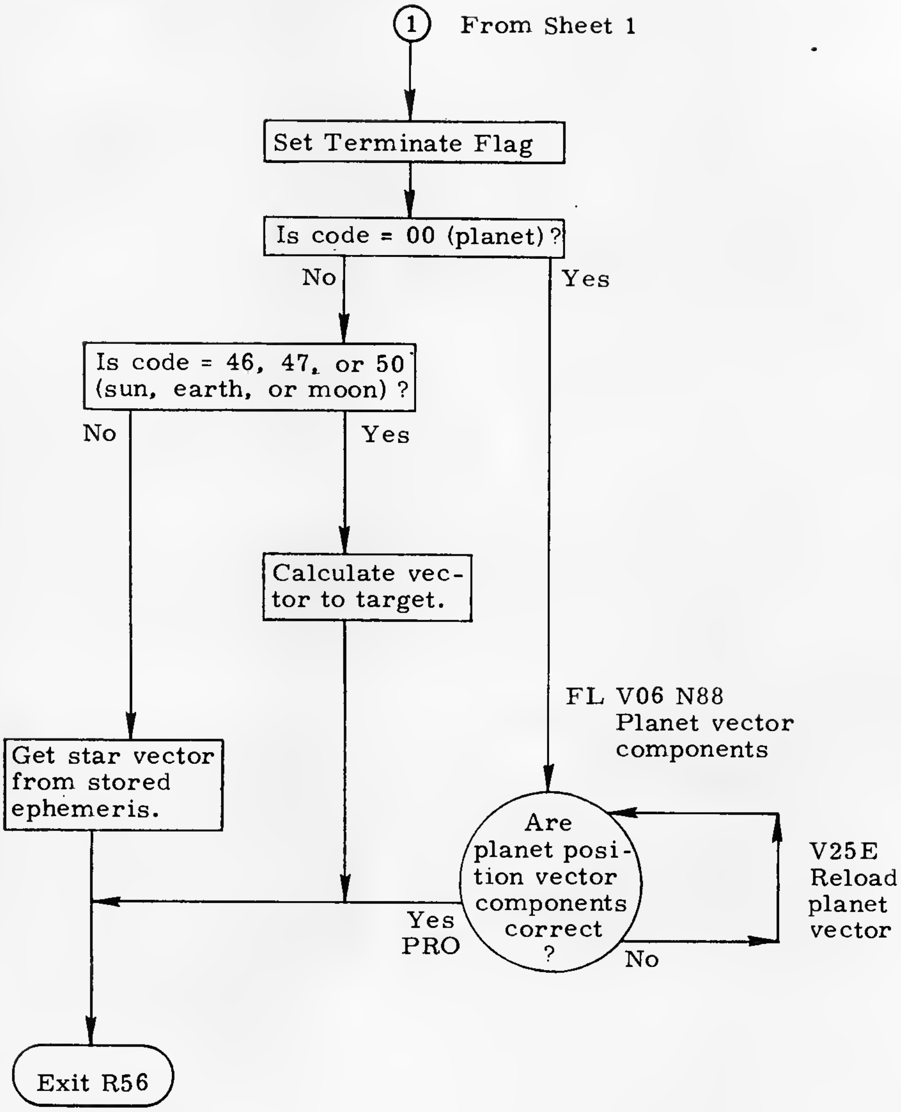

Figure 7.2.3-3. Alternate LOS Sighting Mark Routine (CSM R56) (Sheet 2 of 2)

TABLE 7.2.3-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH

CSM BACKUP IMU ORIENTATION DETERMINATION (CSM P53) (SHEET 1 OF 2)

No.	DSKY	Initiated by	Purpose	Condition	Register	Crew Action
1	V37 ENTR 53 ENTR	Astro-naut	Initiate P53	---	---	---
2	FL V50N25	P53	Request please perform celestial body acquisition	R1 — please perform celestial body acquistion	R1 00015 checklist R2 Blank R3 Blank	Maneuver to acquire celestial body and key PRO to Step 4, or key ENTR to coarse align gimbals to 0, 0, 0
3	V41 N22	P53	Display coarse align gimbal angles	R1, R2, R3 — coarse align gimbal angles	R1 xxx. xx deg R2 xxx. xx deg R3 xxx. xx deg	NO ATT light on, then off, to step 2
4	FL V06 N94	R56	Request response to display of COAS LOS coordinates	R1 — shaft R2 — trunnion	R1 xxx. xx deg R2 xx. xxx deg R3 Blank	Load correct angles and PRO to step 5
5	FL V53 N Blank	R56	Request please perform alternate LOS sighting mark	---	R1 Blank R2 Blank R3 Blank	Center target in reticle image and key ENTR to mark
6	FL V50N25	R56	Request please terminate marks	One mark taken per target R1 -- please perform mark termination	R1 00016 checklist R2 Blank R3 Blank	Mark reject: key ENTR to step 5, or terminate marks; PRO to step 7

TABLE 7.2.3-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH

CSM BACKUP IMU ORIENTATION DETERMINATION (CSM P53) (SHEET 2 OF 2)

No.	DSKY	Initiated by	Purpose	Condition	Register	Crew Action
7	FL V01 N71	R56	Request response to display of celestial body code	R1—celestial body code 00—planet 01/45—star 46—sun 47—earth 50—moon	R1 oooxx R2 Blank R3 Blank	Load correct code. PRO to step 4 after 1st mark (to 8 if code = 00) or to step 9 after 2nd mark (to 8 if code = 00).
8	FL V06 N88	R56	Request response to display of planet position vector	Planet used as target X_{pl} - X component of planet unit position vector at GET in reference coordinates Y_{pl} - same as X_{pl} for Y component Z_{pl} - same as X_{pl} for Z component	R1 .xxxxx X_{pl} R2 .xxxxx Y_{pl} R3 .xxxxx Z_{pl}	Load correct vector. PRO to step 4 after 1st mark or to step 9 after 2nd mark.
9	FL V06 N05	R54	Request response to display of sighting angle difference	Marking completed on two targets. R1—sighting angle difference	R1 xxx.xx deg R2 Blank R3 Blank	To reject and try P53 again, key V32 ENTR to step 2. To accept and terminate P53, key PRO.

7.2.4 P54, Backup IMU Realign—CMC

The Backup IMU Realign Program (P54) realigns the IMU stable member by using a backup sighting device such as the COAS. P54 performs the same function as the IMU Realignment Program (P52), except that P54 can be used in the event of failed MARK pushbutton or optics. (Refer to paragraph 7.2.3 for a description of the COAS.)

7.2.4.1 P54 Computational Sequence

P54's logic flow (Figure 7.2.4-1) is identical to that of P52, except for the following: (a) P54 uses the Alternate LOS Sighting Mark Routine (R56) (Figure 7.2.4-2) instead of the Sighting Mark Routine (R53); (b) the Auto Optics Positioning Routine is not used; (c) the MINKEY plane-change alignment sequence cannot be performed in P54. Table 7.2.4-I lists P54's DSKY activity.

R56 accepts sighting marks, performs celestial-body vector calculations, and requests the astronaut to load the SXT shaft and trunnion angles that would be required to place the SXT LOS along the COAS LOS if the SXT were usable. These angles are needed for the computer to calculate the COAS LOS in vehicle coordinates.

When P54 calls R56, the astronaut sees flashing VERB 06 NOUN 94, requesting the astronaut to approve or correct the backup optics equivalent shaft and trunnion angles. For the COAS, these angles will be approximately 0 deg and 57 deg respectively. When the astronaut is satisfied with these angles, he keys PRO and sees flashing VERB 53 ("Please perform backup-optics sighting mark"). The astronaut orients the CSM to center the celestial body in the COAS reticle image and keys ENTR to mark. The CMC then stores the three gimbal angles, backup-optics angles (loaded under NOUN 94 above), and the time of mark.

The astronaut next sees flashing VERB 50 NOUN 25, check list code 00016 ("Please terminate marking"); he either keys ENTR to erase the mark data and returns to flashing VERB 53 or keys PRO to accept the mark data. The DSKY next flashes VERB 01 NOUN 71 and displays the celestial body code assumed by the CMC for the target which was just marked. This number is corrected via VERB 21 ENTR or approved by PRO.

The CMC tests the value of the approved celestial body code and obtains the value of the body's basic-reference vector in one of three ways: (a) if the code is 00 (planet), the CMC flashes VERB 06 NOUN 88 and displays the assumed value of the

planet's position vector. The vector can be corrected via VERB 25 ENTR or approved by PRO. (b) If the celestial body code is 01 to 45, octal (star), the CMC obtains the star's basic-reference vector from its stored ephemeris data. (c) If the celestial body code is 46, 47, or 50 octal (sun, earth, or moon), the CMC calculates the celestial-body vector based on the time of alignment. The logic flow from this point on is identical to P52, except that R56 is again executed for marking on the second celestial body. Refer to paragraph 7.2.2.3.6 for the remainder of P54's flow.

7.2.4.2 Program Alarms

The program alarms for P54 are identical to those for P52 (paragraph 7.2.2.4), except that those alarms peculiar to R52 or to optics drive operation (00110, 00114, 00115, 00116, 00117, 00120, 00121, and 00404) will not be encountered in P54.

7.2.4.3 Program Coordination and Procedures

Refer to paragraph 7.2.2.5 for a discussion of IMU Realignment Program coordination and to paragraphs 7.2.3.3 and 7.2.3.4 for a discussion of COAS procedures and limitations.

7.2.4.4 Restarts

P54 is restart-protected. Refer to paragraph 7.2.2.6.

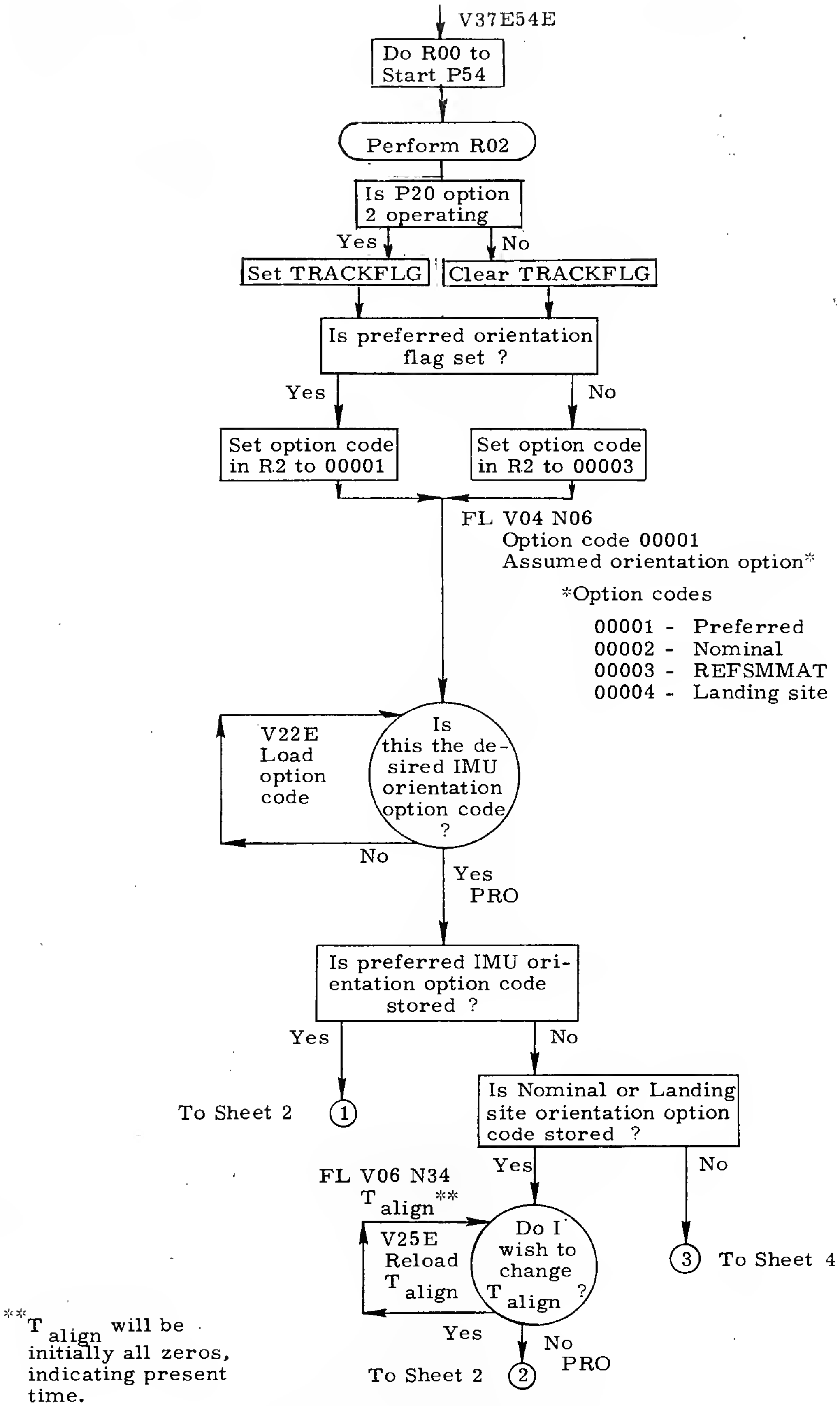

Figure 7.2.4-1. Backup IMU Realign Program (CSM P54) (Sheet 1 of 6)

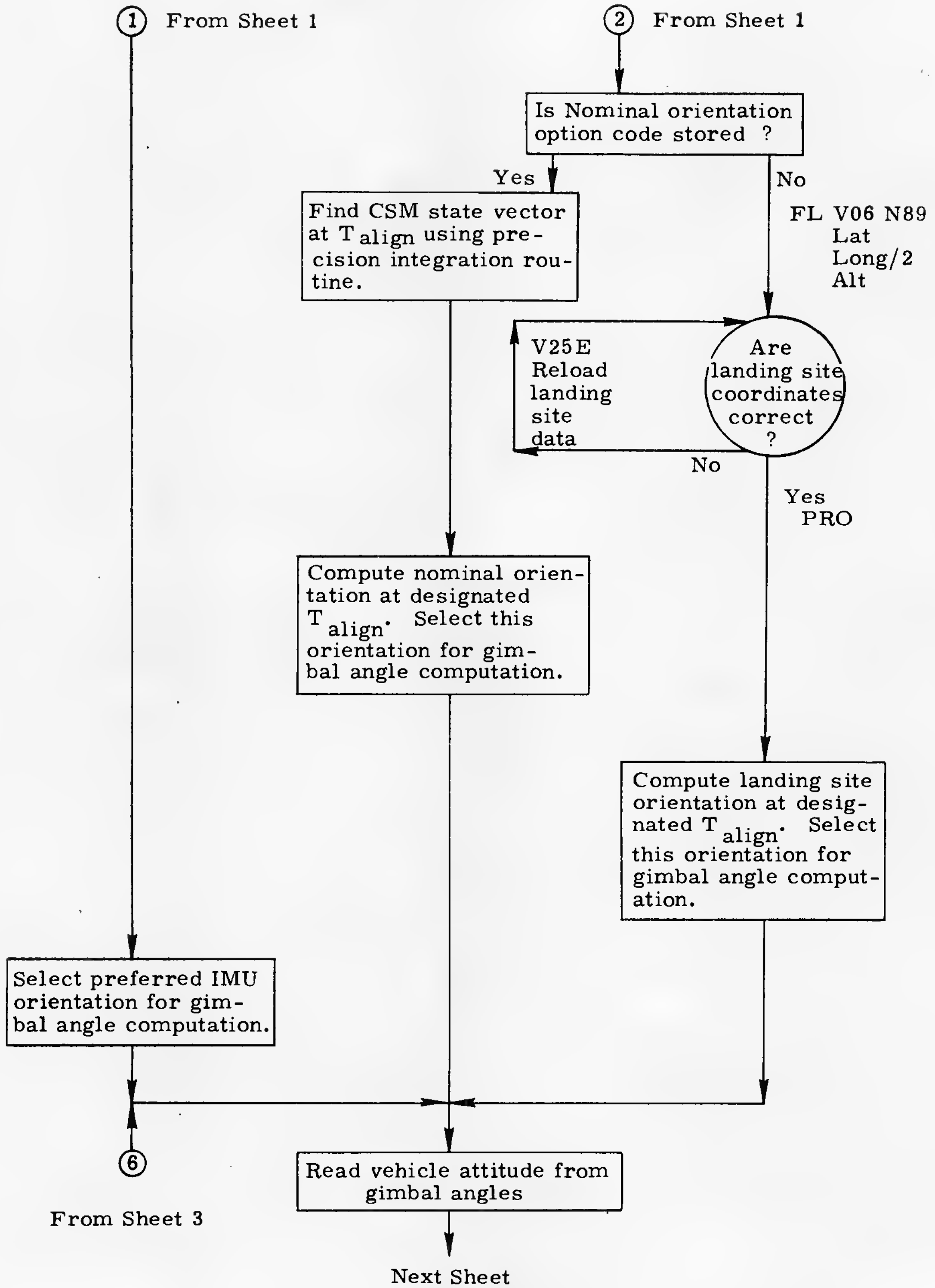

Figure 7.2.4-1. Backup IMU Realign Program (CSM P54) (Sheet 2 of 6)

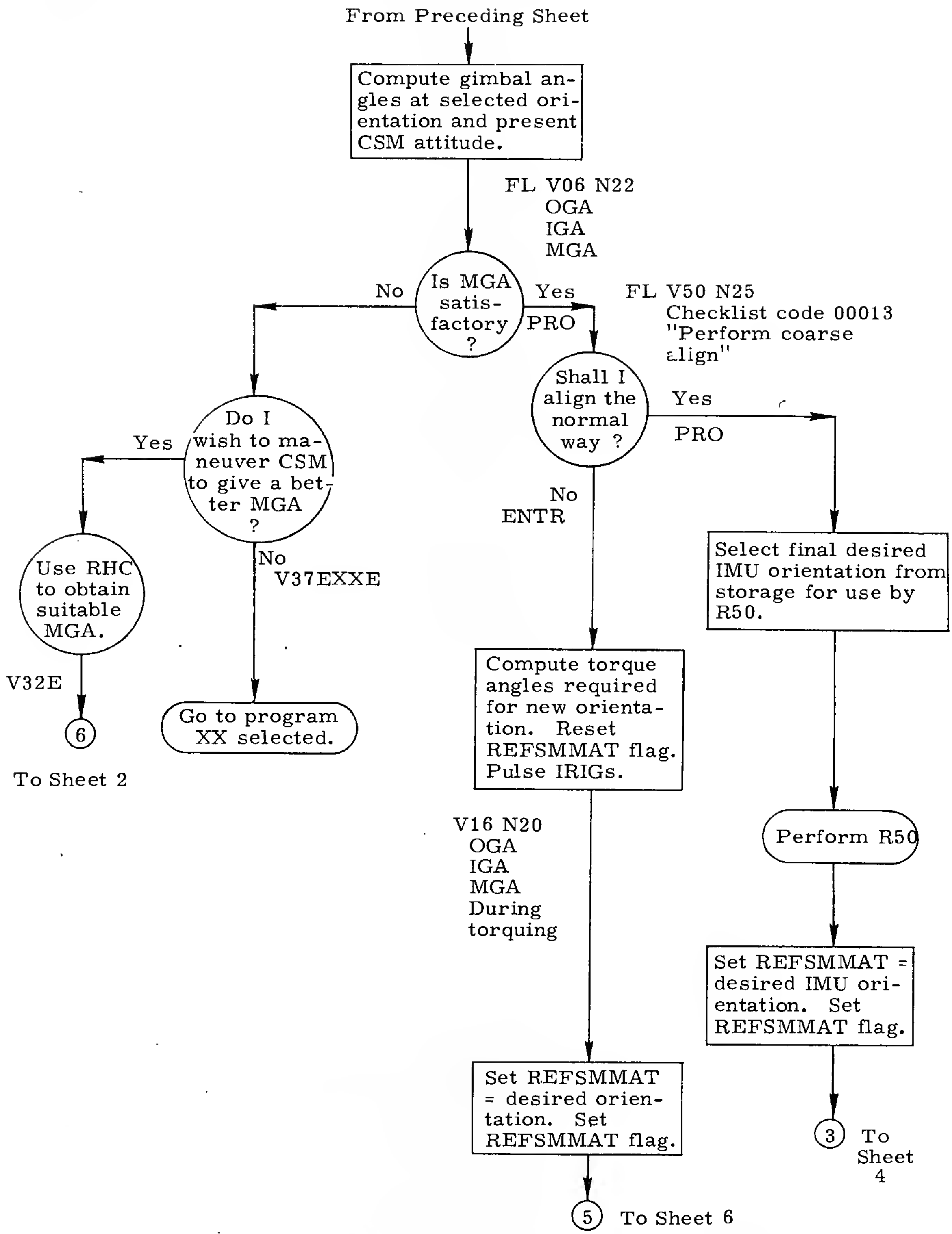

Figure 7.2.4-1. Backup IMU Realign Program (CSM P54) (Sheet 3 of 6)

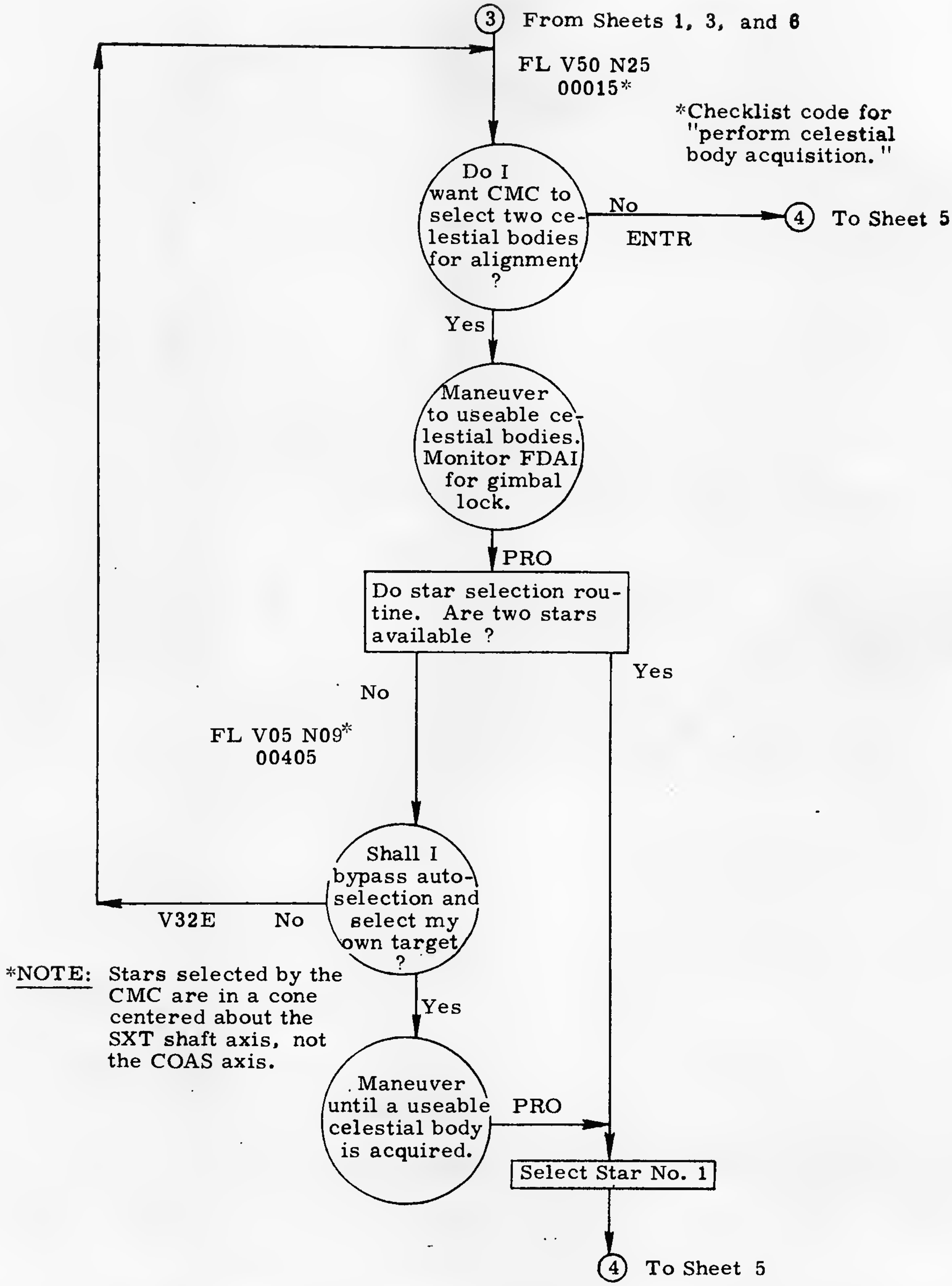

Figure 7.2.4-1. Backup IMU Realign Program (CSM P54) (Sheet 4 of 6)

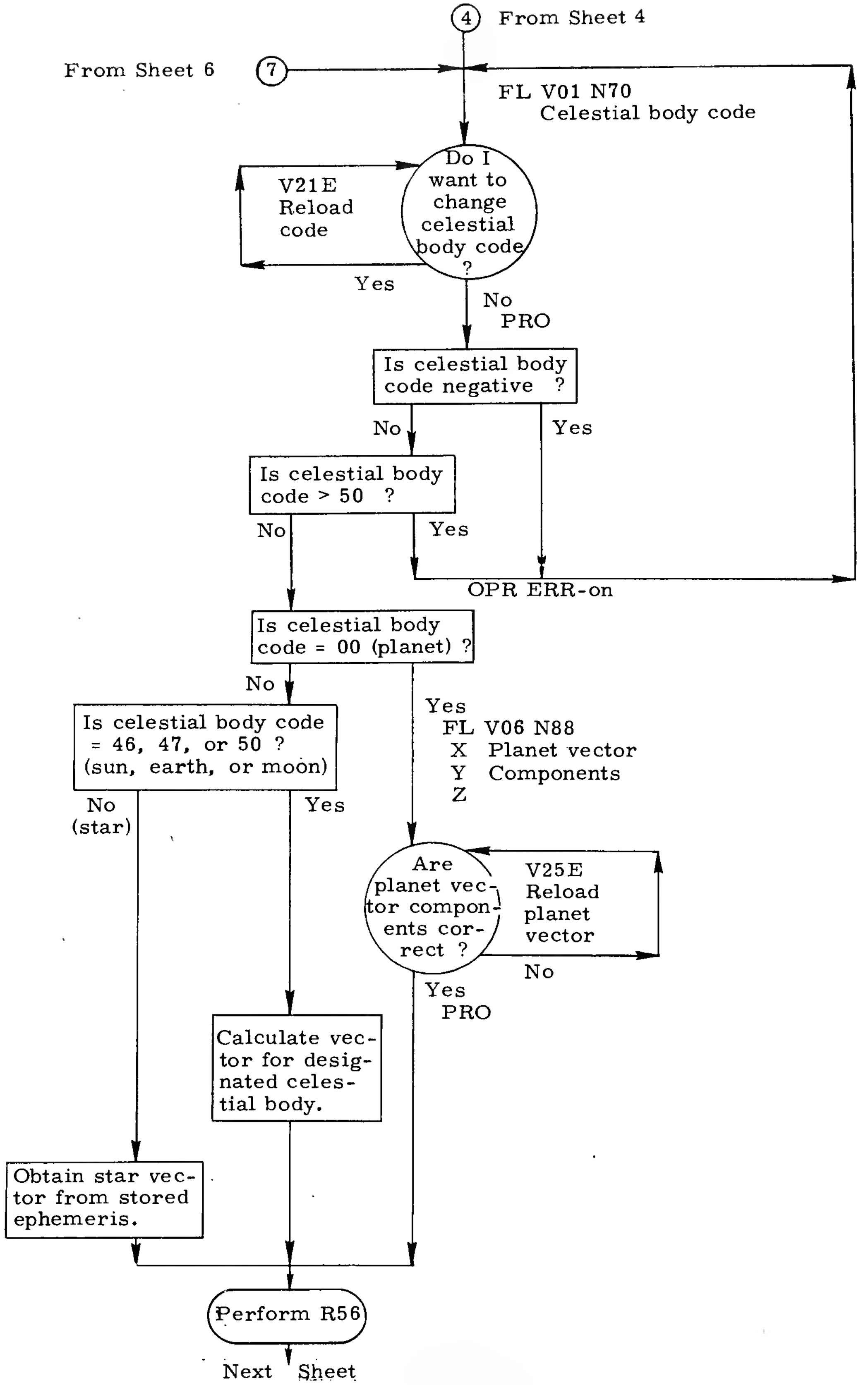

Figure 7.2.4-1. Backup IMU Realign Program (CSM P54) (Sheet 5 of 6)

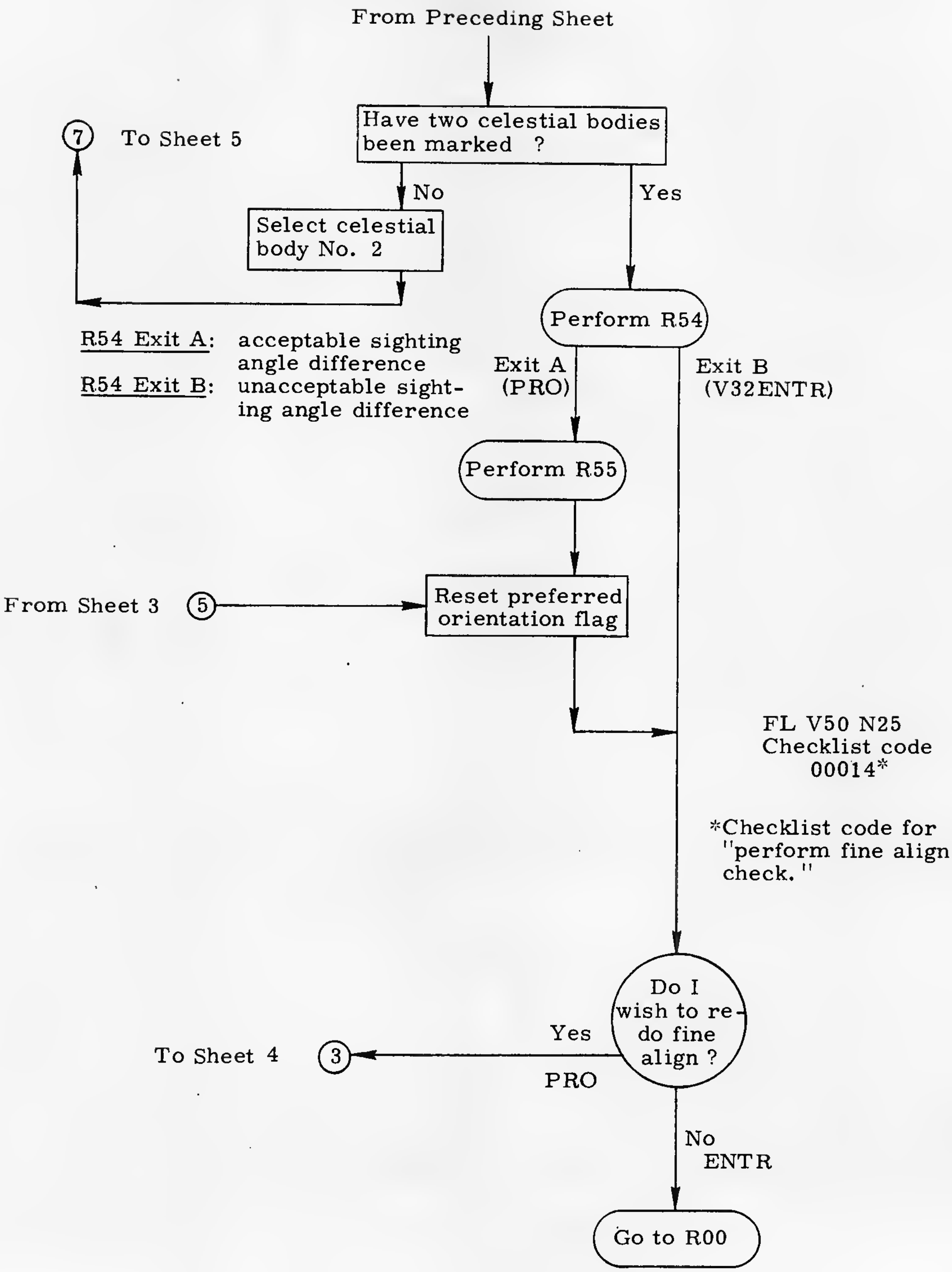

Figure 7.2.4-1. Backup IMU Realign Program (CSM P54) (Sheet 6 of 6)

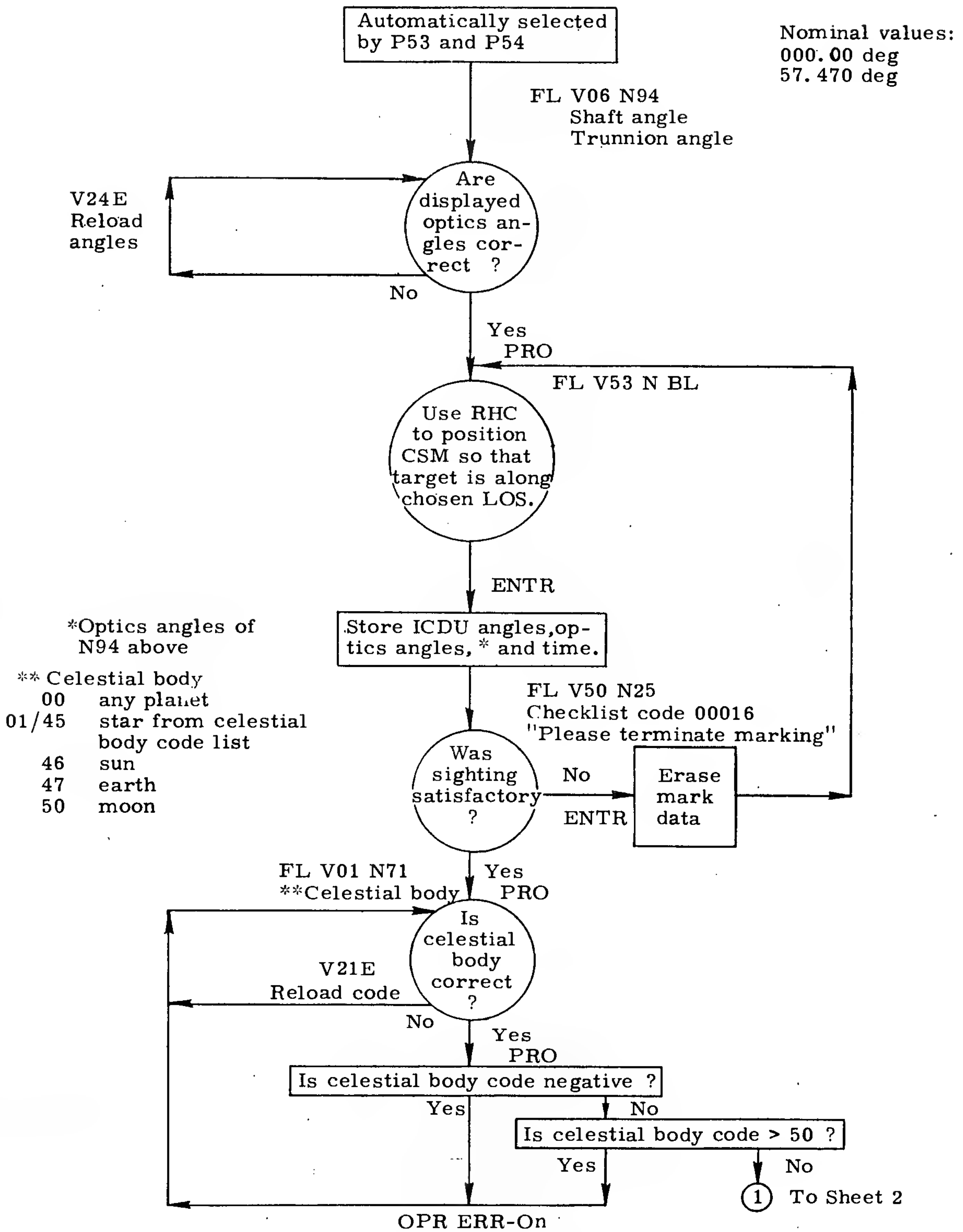

Figure 7.2.4-2. Alternate LOS Sighting Mark Routine (CSM R56) (Sheet 1 of 2)

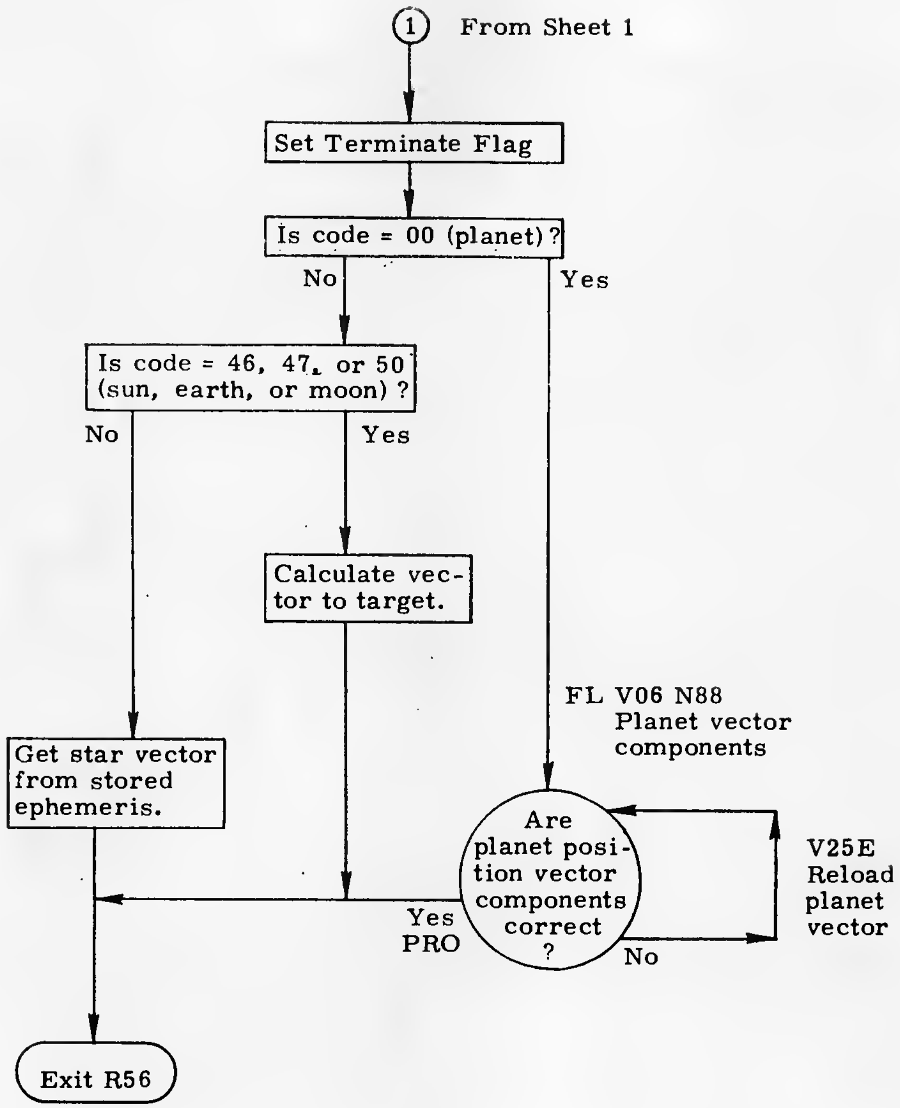

Figure 7.2.4-2. Alternate LOS Sighting Mark Routine (CSM R56) (Sheet 2 of 2)

TABLE 7.2.4-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH

CSM BACKUP IMU REALIGNMENT (P54) (SHEET 1 OF 4)

No.	DSKY	Initiated by	Purpose	Condition	Register	Crew Action
1	V37 ENTR 54 ENTR	Astronaut	Initiate backup IMU realign program	—	—	—
2	FL V04 N06	P54	Request response to display of option code	IMU orientation known R1 — please specify IMU orientation R2 — option assumed by CMC 00001 = preferred 00002 = nominal 00003 = REFSMMAT 00004 = landing site	R1 00001 checklist R2 oooox R3 Blank	preferred - PRO to 5 nominal - PRO to 3 REFSMMAT - PRO to 8 landing site - PRO to 3
3	FL V06 N34	P54	Request response to display of time of alignment (T align)	Nominal or landing site options. R1, R2, R3 — time of alignment in GET; all zeroes = present time	R1 00xxx. hr R2 000xx. min R3 0xx.xx sec	Load GET. PRO to 5 for nominal, 4 for landing site option
4	FL V06 N89	P54	Request response to display of landing site coordinates	Landing site option R1 — latitude (+ North) R2 — longitude/2 (+East) R3 — altitude above mean lunar radius	R1 xx.xxx deg R2 xx.xxx deg R3 xxx.xx n mi.	PRO to 5
5	FL V06 N22	P54	Request response to display of gimbal angles after coarse alignment at present CSM attitude	All option except REFSMMAT R1 — outer gimbal R2 — inner gimbal R3 — middle gimbal	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg	If middle gimbal angle ≥70 deg, maneuver and V32 ENTR to 5. PRO to 6 if angles satisfactory.

TABLE 7.2.4-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH

CSM BACKUP IMU REALIGNMENT (P54) (SHEET 2 OF 4)

No.	DSKY	Initiated by	Purpose	Condition	Register	Crew Action
6	FL V50 N25	P54	Request crew to perform normal or pulse torque coarse align	Proposed gimbal angles satisfactory R1 — Perform normal or gyro torque coarse align	R1 00013 checklist R2 Blank R3 Blank	Normal coarse align — PRO (No ATT light on, then off, to 8). Torque — CMC Mode to FREE, ENTR to 7
7	V16 N20	P54	Monitor gimbal angles during torquing	R1 — outer gimbal R2 — inner gimbal R3 — middle gimbal	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg	When torquing complete, to 18
8	FL V50 N25	P54	Please perform celestial body acquisition	Normal coarse align accomplished R1 — Perform celestial body acquisition Note: Star selection routine not useful for COAS sightings.	R1 00015 checklist R2 Blank R3 Blank	Maneuver if needed. Computer select stars — PRO to 9. Manual acquisition — ENTR to 9. (If alarm 00405 and crew finds star, PRO to 9. If alarm and computer to try again, maneuver and V32 ENTR to 8.)
9	FL V01 N70	P54	Display celestial body identification code.	Celestial body acquired R1 — 00000 = any planet 00001 to 00045 = star 00046, 47, 50 = sun, earth, moon	R1 oooxx celestial body code R2 Blank R3 Blank	PRO to 11 (to 10 if xx = 00).

TABLE 7.2.4-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH

CSM BACKUP IMU REALIGNMENT (P54) (SHEET 3 OF 4)

No.	DSKY	Initiated by	Purpose	Condition	Register	Crew Action
10	FL V06 N88	P54	Request response to display of planet vector	Celestial body code = 00000 R1 — X - component of planet unit R2 — same as R1 for Y R3 — same as R1 for Z	R1. xxxxx X_{pl} R2. xxxxx Y_{pl} R3. xxxxx Z_{pl}	Load vector. PRO to 11.
11	FL V06 N94	R56	Request response to display of backup optics equivalent shaft and trunnion angles	R1 — equivalent shaft angle R2 — equivalent trunnion angle	R1 xxx. xx deg R2 xx. xxx deg R3 Blank	Load angles. PRO to 12.
12	FL V53	R56	Request mark	—	R1 Blank R2 Blank R3 Blank	Maneuver to center target in backup optics. Key ENTR to mark. To 13.
13	FL V50 N25	R56	Request terminate marking	R1 — please terminate marking	R1 00016 checklist R2 Blank R3 Blank	Mark reject--ENTR to 12. Accept--PRO to 14.
14	FL V01 N71	R56	Request response to display of celestial body code	R1 — celestial body code	R1 oooxx R2 Blank R3 Blank	Check code. PRO to 9 after first mark(to 15 if xx = 00) or PRO to 16 after second mark (to 15 if xx = 00)

TABLE 7.2.4-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH

CSM BACKUP IMU REALIGNMENT (P54) (SHEET 4 OF 4)

No.	DSKY	Initiated by	Purpose	Condition	Register	Crew Action
15	FL V06 N88	R56	Request response to display of celestial body vector	Celestial body code = 00	R1. xxxxx X_{pl} R2. xxxxx Y_{pl} R3. xxxxx Z_{pl}	Check vector. PRO to 9 after first mark or PRO to 16 after second mark.
16	FL V06 N05	R54	Request response to sighting angle difference	Two celestial bodies have been marked. R1 — difference between actual and measured angle between two celestial bodies	R1 xxx.xx deg R2 Blank R3 Blank	Reject--V32 ENTR to 18. Accept--PRO to 17.
17	FL V06 N93	R55	Request response to proposed torquing angles for fine alignment	Sighting angle difference O.K. R1 — outer gimbal R2 — inner gimbal R3 — middle gimbal torquing angles	R1 xx.xxx deg R2 xx.xxx deg R3 xx.xxx deg	Torque--CMC Mode to FREE and PRO to 18. Bypass--V32 ENTR to 18.
18	FL V50 N25	P54	Request third star check	R1 — please perform third star fine align check	R1 00014 checklist	Recheck--PRO to 8. Bypass and terminate P54--ENTR.

7.3 LGC ALIGNMENT PROGRAMS

The LM guidance computer alignment programs (P51 and P52) perform the same functions as the corresponding CSM programs. The most important differences between the CSM and LM programs arise from the use of the LM alignment optical telescope (AOT) for celestial-body sightings in place of the CSM SXT and SCT. These differences are discussed in paragraphs 7.3.1 and 7.3.2.

The Lunar Surface Alignment Program (P57), has a number of features that differ from the other alignment programs. In addition to realigning the IMU during the LM lunar-surface phase, P57 also computes and stores the landing-site vector ($\underline{R}_{LS}$) and the LM attitude relative to the moon. P57 performs these tasks using not only celestial-body sightings, but also by sensing the direction of the local-gravity vector. The following paragraphs describe the general sequence of PGNCS activity between lunar touchdown and liftoff. Refer also to Figure 7.3-1.

For the nominal LM mission, only two stable-member orientations are used: one from DOI through landing, and the other from liftoff through docking. At touchdown, the stable member is in the orientation defined by the intended landing site, which may differ slightly from the actual landing site. The Landing Phase (ROD) Program (P66) has LGC control. An abort at this time, if required, is performed by the Ascent Propulsion System Abort Program (P71). At about three minutes after touchdown, the first STAY/NO STAY decision is made. If the decision is STAY, the LM crew selects the Landing Confirmation Program (P68).

As soon as P68 is entered, P71 can no longer be used for liftoff; the crew must use the Nominal Ascent Program (P12) for launch. In preparing for a possible P12 ascent at the second STAY/NO STAY decision (10 minutes after touchdown), P68 terminates the landing programs and stores the final LM position on the lunar surface (in moon-fixed coordinates) as $\underline{R}_{LS}$. P68 also stores the orientation of the LM Y- and Z-axes in moon-fixed coordinates. If required, P57 can, using only the LM attitude vectors stored by P68, realign the stable member to a desired P12 liftoff orientation. About five minutes after touchdown, after executing P68, the crew enters P12 and prepares for the second STAY/NO STAY decision.

At 10 minutes after touchdown, if the decision is to stay on the lunar surface, the LM crew terminates P12 and proceeds with post-landing systems checkout. About 20 minutes after touchdown, the astronaut selects P57 to determine the direction of the local-gravity vector in navigation-base coordinates. No celestial-body sightings are taken at this time, and the stable member's orientation is not changed. The

LGC now has an accurately measured representation of the local vertical in relation to the LM. If necessary, the LGC can accomplish a fast P57 realignment to the local vertical by merely driving the IMU to the desired orientation.

About 30 minutes after touchdown, the astronaut takes sightings on two celestial bodies to perform a P57 realignment to the REFSMMAT used for landing. During this alignment, P57 calculates $\underline{R}_{LS}$ by using the gravity vector calculated by the previous P57. With ground approval, the new $\underline{R}_{LS}$ replaces the $\underline{R}_{LS}$ previously stored in the LGC. The gyro torquing angles of this alignment provide a check on the IMU drift since the previous alignment prior to PDI. If, from sightings on two stars, it is determined that the IMU has a drift rate greater than 1.5 deg per hour, the crew should plan to use the abort guidance system for ascent.

After this alignment, P57 is selected again for another set of celestial-body sightings for additional landing-site determination by the ground. The LGC then receives a P27 update, and the crew performs P22 lunar-surface tracking of the CSM. The IMU and LGC are then switched to standby.

In preparing for ascent, the pitch component of the stable member's orientation must be accurate, because any errors will directly affect the flightpath angle and the resulting insertion orbit. The orientation error limit for a safe orbit is about 0.5 deg. As long as the stable member's orientation is correct with respect to the local-gravity vector (assumed parallel to the true local vertical), a good flightpath angle will result, even though the LGC-stored value of $\underline{R}_{LS}$ may be in error.

About three hours before lunar liftoff, the IMU and LGC are powered up. A P57 realignment to the landing site's inertial orientation at the planned liftoff time is then performed using measurements of the local gravity vector and the line-of-sight to one celestial body. This alignment provides an inertial reference for the following P22 rendezvous-radar tracking of the CSM and gives a good indication of any LM settling since the first P57 gravity vector measurement.

The IMU is realigned to the liftoff REFSMMAT at 45 minutes before liftoff. For this realignment, P57 uses the gravity vector and one celestial body. A drift check based on this alignment is used by the LM crew and ground to determine the best guidance system for liftoff. At 20 minutes before liftoff, if the PGNCS is performing satisfactorily, the crew enters P12 and carries out the ascent procedures. Finally, about 25 minutes after lunar liftoff, a P52 realignment to the liftoff REFSMMAT is performed to ensure navigation accuracy during rendezvous.

APPROXIMATE TIME FROM LM TOUCHDOWN (HR:MIN)	EVENT
-05:30	DOCKED IMU ALIGNMENT (REFER TO PARAGRAPH 7.3.2.5.3)
-03:30	LM P52 REALIGN TO REFSMMAT (OPTION 3)
-01:30	LM P52 REALIGN TO REFSMMAT (OPTION 3)
-00:12	POWERED DESCENT INITIATION
00:00	TOUCHDOWN; TILT-OVER ABORT DECISION
00:03	FIRST STAY/NO-STAY DECISION; P68 IF STAY
00:05	ENTER P12
00:10	SECOND STAY/NO-STAY DECISION; EXIT P12 IF STAY
00:20	LM P57, GRAVITY VECTOR DETERMINATION ONLY; NO STABLE-MEMBER REORIENTATION. (PARTIAL AT-1, OPTION 3)
00:30	LM P57, TWO CELESTIAL BODY REALIGN TO REFSMMAT (AT-2, OPTION 3)
00:50	LM P57, REPEAT AT-2, OPTION 3
01:20	STAY/NO STAY FOR LUNAR STAY
01:45	LM P22
02:00	IMU AND LGC TO STANDBY

APPROXIMATE TIME FROM LM LIFTOFF (HR:MIN)	EVENT
-03:00	IMU AND LGC POWERED UP
-02:30	LM P57 GRAVITY AND ONE CELESTIAL BODY ALIGNMENT TO LANDING SITE (AT-3, OPTION 4)
-02:05	LM P22
-00:45	LM P57 REALIGN (AT-3, OPTION 3)
-00:20	P12; LOAD ASCENT PARAMETERS
-00:00	LIFT-OFF
00:25	LM P52 REALIGN TO REFSMMAT (OPTION 3)
03:45	DOCKING

Figure 7.3-1. Timeline of Typical LM Alignment Activity

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7.3.1 P51, IMU Orientation Determination Program—LGC

The IMU Orientation Determination Program (P51) is used during free fall to determine the present IMU stable member orientation with respect to the Basic Reference Coordinate System and the associated REFSMMAT. This is accomplished by sighting on two navigation stars, or known celestial bodies, with the Alignment Optical Telescope (AOT) or the Crew Optical Alignment Sight (COAS).

The astronaut acquires the desired celestial bodies by maneuvering the LM until the bodies are visible in the optical sighting device. He identifies the two celestial bodies and takes up to five X and Y marks on each. After the sightings have been made on both celestial bodies, the LGC has the unit line-of-sight (LOS) vectors for the two bodies, in IMU stable member coordinates. These vectors are compared with the stored vectors in the Basic Reference Coordinate System, and the angle difference is displayed to the crew to either accept or reject and repeat the sightings.

In addition to IMU orientation determination information, P51 also displays the difference angle between the actual and measured lines of sight.

The displays during the IMU orientation determination program are listed in Table 7.3.1-I.

7.3.1.1 Related Routines

P51 has the following four related routines:

a. AOT Mark Routine (R53)
b. Sighting Data Display Routine (R54)
c. Markrupt Routine (R57)
d. Celestial Body Definition Routine (R58).

The AOT Mark Routine (R53) is called automatically by P51 and is used to request and process sighting marks (using the AOT or COAS) on two celestial bodies specified by the crew. R53, by requesting the mark (i.e., the depressing of the MARK X, MARK Y, or MARK REJECT pushbutton), calls the Markrupt Routine (R57) to accept and process the crew inputs associated with the orientation determination process. R53 is called two times by P51 to establish measurement data on two different celestial bodies. With the measured star vectors from R53 and R57, the Celestial Body Definition Routine (R58) establishes the actual celestial body position vectors

TABLE 7.3.1-I

DSKY DISPLAYS ASSOCIATED
WITH LM IMU ORIENTATION DETERMINATION (LM P51)
(Sheet 1 of 2)

No.	DSKY	INITIATED BY	PURPOSE	CONDITION	REGISTER	CREW ACTION
1	Verb 37 ENTR 51 ENTR	Astronaut	Start P51	- - -	- - -	- - -
2	FL Verb Noun 25	P51	Request Perform Celestial Body Acquistion	- - -	R1 00015 Check List R2 Blank R3 Blank	Acquire target. PRO to 3. To coarse align IMU to 0, 0, 0, key ENTR. PRO to 3.
2a	Observe Verb 41 Noun 22 all zeroes.	P53	Display coarse align gimbal angles.	R1, R2, R3—coarse align gimbal angles	R1 xxx. xx deg R2 xxx. xx deg R3 xxx. xx deg	NO ATT light on, then off, to step 2
3	FL Verb 01 Noun 71	R53	Request Load Celestial Body and Detent Codes	Astronaut Ready to Mark. C = detent code DE = Celestial Body Code C = 1 - Left fwd 2 - Front 3 - Right fwd 4 - Right rear 5 - Rear 6 - Left rear 7 - COAS	R1 00CDE R2 Blank R3 Blank	Load R1. PRO to 4 (to 3a if C = 7)

TABLE 7.3.1-I

DSKY DISPLAYS ASSOCIATED

WITH LM IMU ORIENTATION DETERMINATION (LM P51)

(Sheet 2 of 2)

3a	FL Verb 06 Noun 87	R53	Request Load COAS azimuth and Elevation	C = 7: (Az, El = +00000, +00000-fwd or +00000, +09000 overhead)	R1 xxx.xx deg R2 xxx.xx deg R3 Blank	Load Az, El; PRO to 4
4	FL Verb 54 Noun 71	R53	Request mark using X or Y button	Celestial Body Code Specified, 1000x in R2 or R3 indicates which register's marks can be rejected DE- - Celestial Body Code	R1 00CDE R2 X marks R3 Y marks	Key ENTR to change reject option from one register to another. Key Verb 32 ENTR to 3 to redesignate celestial body. Key PRO to 5 when marks complete. If DE=00 PRO to 4a.
4a	FL Verb 06 Noun 88	R58	Request Load planet unit vector components	DE = 00 (planet)	R1 .xxxxx R2 .xxxxx R3 .xxxxx	Load vector values. PRO to 3 after first target; to 5 after second target.
5	FL Verb 06 Noun 05	R54	Display Sighting Angle Difference	R1- - Sighting Angle Difference	R1 xxx.xx deg R2 Blank R3 Blank	To return to start of P51, Key Verb 32 ENTR. To approve value, Key PRO to FL Verb 37.

to be used for the IMU orientation determination. The Sighting Data Display Routine (R54) then calculates the difference between the actual and measured sighting angles and displays this information to the crew. The astronaut then decides whether or not to continue with the orientation determination or to take new sightings and start the process again.

7.3.1.2 Options

To complete P51 the astronaut has the option of using either the AOT or the COAS in determining the IMU orientation. The operation of the COAS within the program is described in paragraph 7.3.1.3.

7.3.1.3 Logic Flow Description

The astronaut selects the IMU Orientation Determination Program by keying VERB 37 ENTR 51 ENTR into the DSKY. (See Figure 7.3.1-1.) He should immediately ensure that the AOT lamp circuit breaker is closed so that the reticle is properly illuminated. The program immediately checks to determine whether the inertial subsystem (ISS) is on. If the ISS is not on, the PROG alarm light comes on and the LGC exits P51. (See paragraph 7.3.1.4, alarm code 00210.) In order to reenter P51, the program has to be reinitiated as described above. If the ISS is on, the DSKY displays a flashing VERB 50 NOUN 25, requesting a "please perform celestial body acquisition"– indicated by 00015 in R1. (See Table 7.3.1-I.)

At this point, the crew must decide whether they will maneuver the LM such that the inner-gimbal axis is in the preferred direction (stable member X-axis in the thrust direction) or such that there are two celestial bodies visible in the optical system (AOT or COAS) field of view. In either case, they must be sure to monitor the FDAI ball as they maneuver the LM to ensure that gimbal lock is not impending. Gimbal lock occurs when the middle gimbal angle exceeds ±85 degrees from its zero position. The gimbal lock warning light, however, is illuminated when the angle exceeds 70 degrees from zero. If 85 degrees is exceeded, the LGC automatically commands a coarse align to prevent gimbal oscillation. If gimbal lock is impending, or if the astronaut desires, he can coarse-align the IMU to 0, 0, 0, gimbal angles. If gimbal lock is not impending or the astronaut does not desire to coarse align the IMU, he can key in PRO and the program will go directly to the AOT Mark Routine (R53). If the astronaut desires to coarse-align, he can key in ENTR and immediately obtain a VERB 41 NOUN 22 display. (See Table 7.3.1-I.) This display shows the ICDU/gimbal angles to which the IMU should be aligned. The angles should be all zeros. He will also see the NO ATT light come on, indicating that the IMU is in

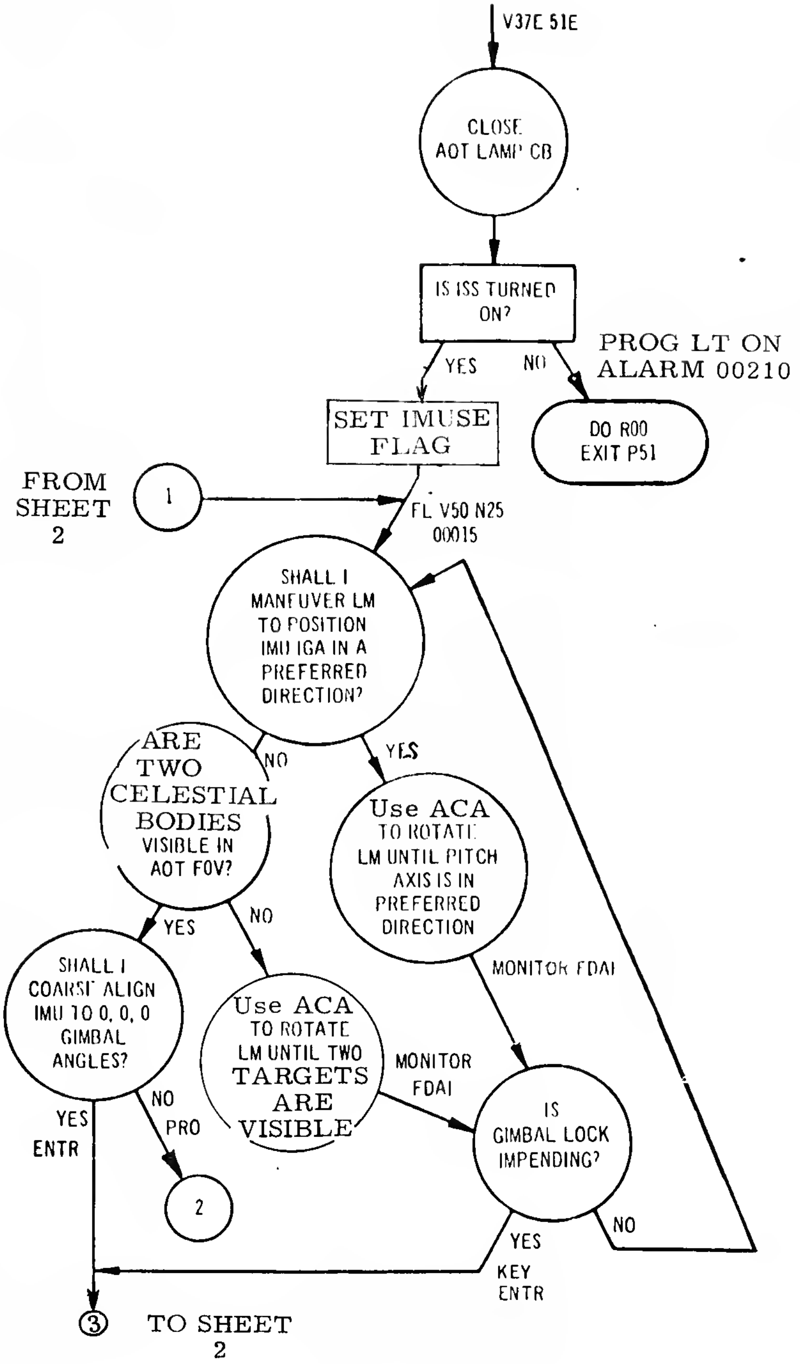


Figure 7.3.1-1. IMU Orientation Determination Program (LM P51) (Sheet 1 of 2)

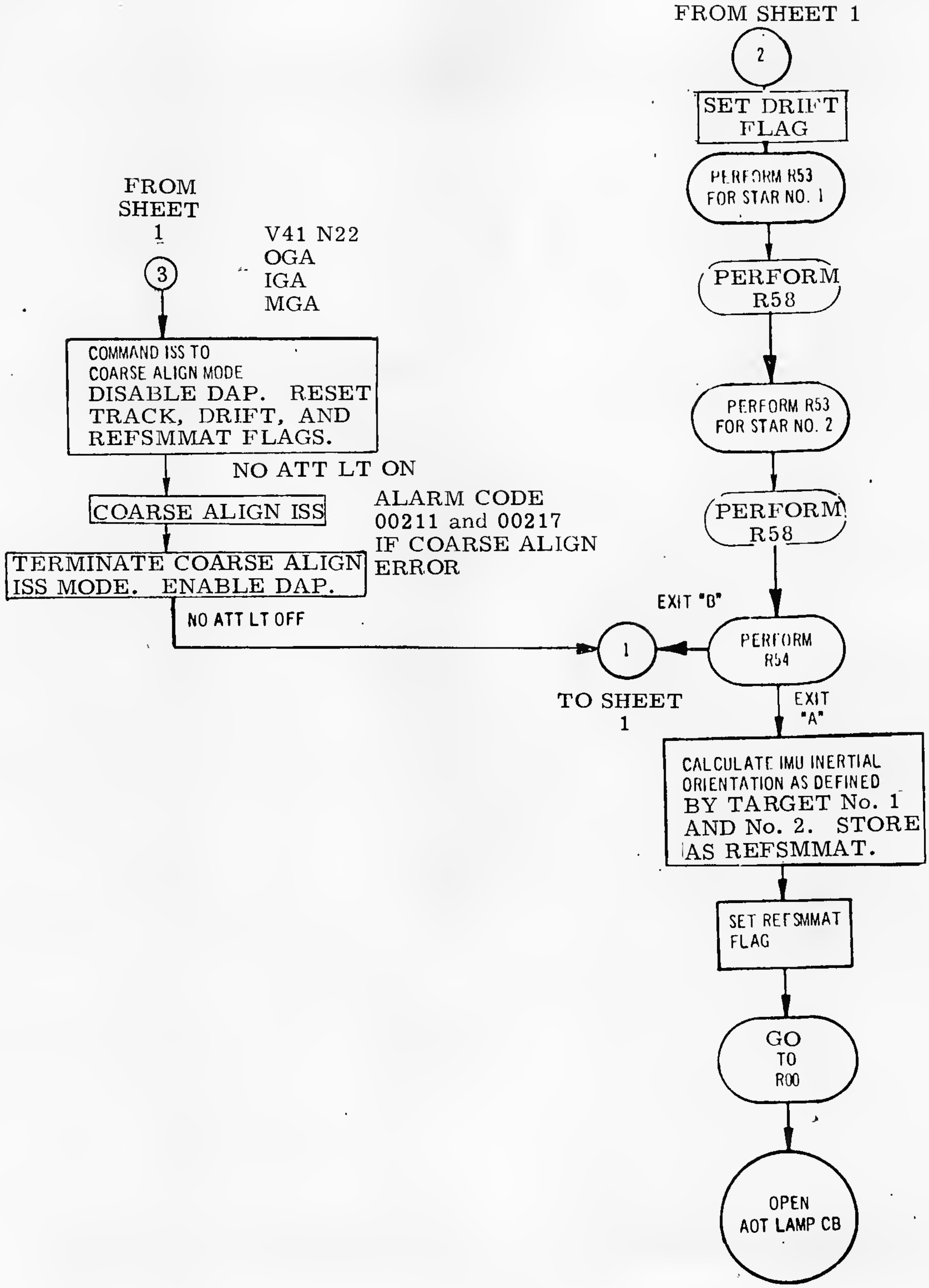


Figure 7.3.1-1. IMU Orientation Determination Program (LM P51) (Sheet 2 of 2)

the Coarse Align Mode. When coarse alignment is complete, the LGC turns off the NO ATT light. If, upon completion of coarse-align, the gimbals are not within ±2 degrees of the desired 0 degree, the PROG alarm light will come on (see paragraph 7.3.1.4, alarm codes 00211 and 00217). Should either of these alarms come up, the IMU would have to be coarse-aligned again. When the IMU is within ±2 degrees of the desired 0 degree, the astronaut should key in PRO on the flashing VERB 50 NOUN 25 display. This will allow the program to go to the AOT Mark Routine (R53).

The AOT Mark Routine (R53) processes the sighting marks on the celestial bodies. Upon initial entry into R53, several checks are made by the LGC to determine if it is possible to use the routine at this time. (See paragraph 7.3.1.4, alarm codes 31211, and 31207.) The first display the astronaut sees in this routine is a flashing VERB 01 NOUN 71, indicating the AOT detent and star code. (See Table 7.3.1-I.) If these codes are correct for the present sightings, he should key in PRO. If these codes are not correct for the present sightings, the crew should key in VERB 21 ENTR, load the correct codes, and then key in PRO. For the present, assume that the detent code is other than a zero or seven. A zero code is invalid in R53, and a seven code indicates that the crew should use the backup (COAS) system. The use of the COAS is described later.

On the PRO, the next display the crew sees is a flashing VERB 54 NOUN 71, requesting a "Please perform a mark X or mark Y reticle line/star intersection." Before putting up this display, the computer picks up azimuth and elevation calibrations and apparent rotation compensation for the specified detent position, and computes the X and Y mark-plane vectors and the optical-axis vector. LGC also zeros the mark identifier and mark counters. The mark identifier is a special internal register that identifies whether the mark is X or Y. The counters are special registers to count the X and Y marks. Before taking any marks, the crew must adjust the AOT reticle to zero. A mark is then made by (1) maneuvering the LM such that the target body crosses the X or Y reticle line, and (2) depressing the appropriate mark pushbutton.

The astronaut may make up to 5 X marks and 5 Y marks in any sequence. The mark counters in registers R2 and R3 maintain a count of the accumulated X and Y marks. If more than 5 marks are made, the gimbal angles stored by the fifth mark will be over written by the sixth mark. The mark counter will remain at 5. A pointer was added to the mark counter registers so the astronaut will always be aware of what his last mark was. This was primarily for MARK REJECT purposes because the last mark will be rejected first. This pointer is a 1 in the high digit of the mark

counter register of the mark just performed. An example: if the astronaut had made 2 Y marks and had just performed the fourth X mark, the display would look like:

VERB 54 NOUN 71
R1 00CDE
R2 10004
R3 00002

The reject pointer indicates an X mark was made and will be rejected with a MARK REJECT action. If that were the case R2 would be 10003 and further reject action would reduce the R2 counter to 10000 and cause ALARM 115 when there were no more X marks to be rejected. To give the astronaut some control of the reject action, a switch was provided with the ENTR button. Depressing the ENTR button changes the reject pointer to the opposite mark counter. An example: if the astronaut wanted to reject a Y mark in the above display, he would first depress the ENTR button to display:

VERB 54 NOUN 71
R1 00CDE
R2 00004
R3 10002

The reject action would now cause R3 to be 10001. During inflight alignments the position of the reject pointer in no way affects any sequence of marking the astronaut may wish to make.

If the astronaut wants to erase all the marks taken and start over, he keys VERB 32 ENTR on the VERB 54 NOUN 71 display. Keying PRO on this display allows the LGC to calculate the LOS vector to the celestial body, starting with the most recent complete pair of X and Y mark data and averaging them with the previously computed LOS vector to the body. It is not necessary that the same number of X and Y marks be made; however, the number of star vectors computed and averaged will be equal to the least number of X or Y marks made.

After one pair of marks, the astronaut has the following options: (1) to terminate the marking by keying in PRO; (2) to continue marking on the same celestial body (if less than 5 X and 5 Y marks are already stored in the LGC) by using the appropriate mark buttons; (3) to discard all data on the present celestial body by keying in VERB 32 ENTR, select a new celestial body and continue marking on the new body;

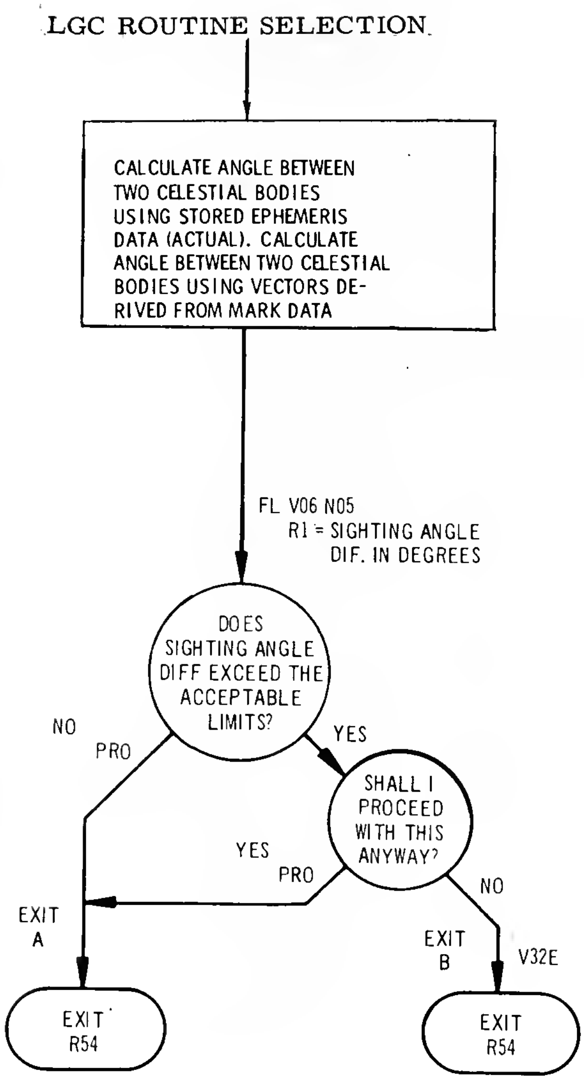


Figure 7.3.1-2. Sighting Data Display Routine (LM R54)

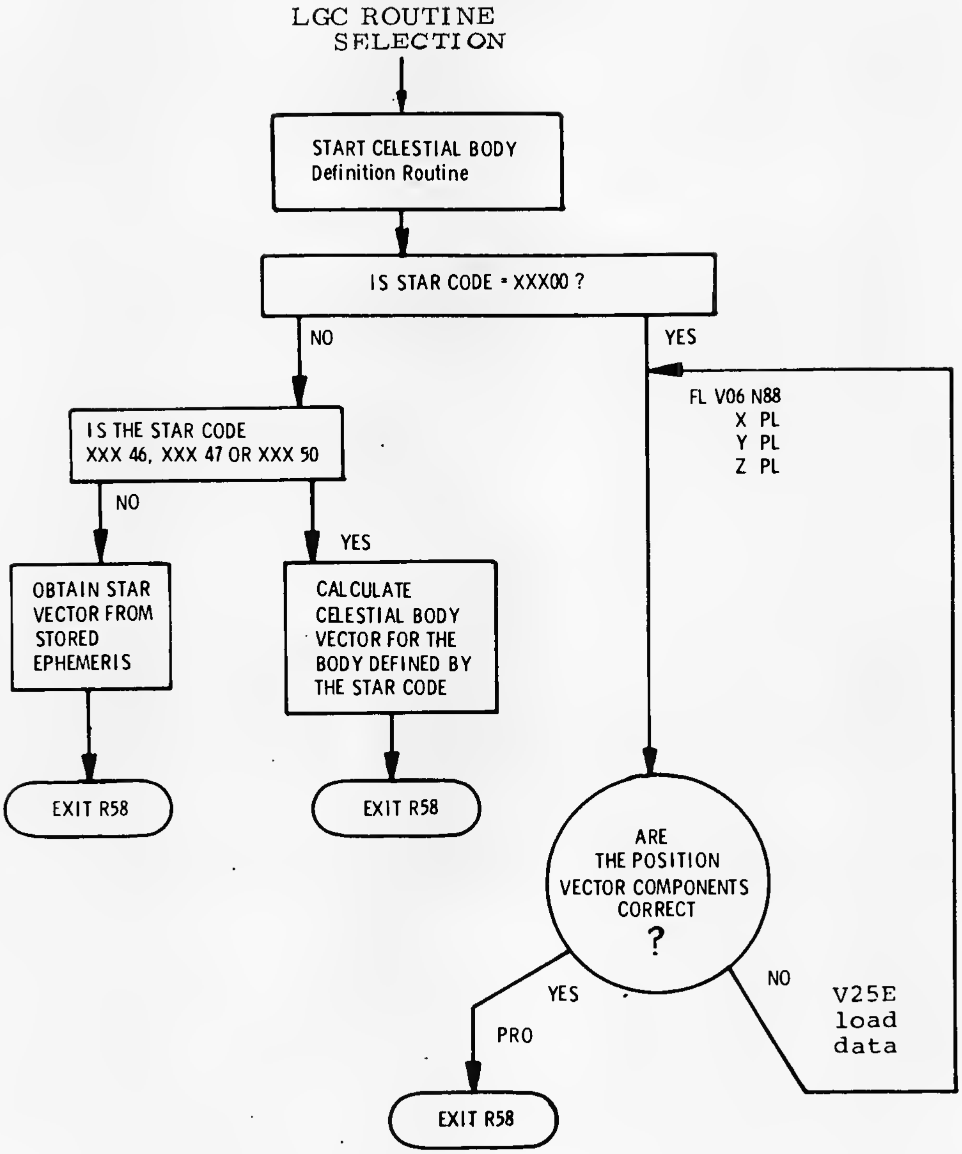


Figure 7.3.1-3. Celestial Body Definition Routine (LM R58)

or (4) to terminate the whole alignment by keying in VERB 34 ENTR (terminate). If at least one pair of marks has not been performed when a PRO is executed, the LGC will store alarm code 00111 and illuminate the PROG alarm light.

This marking procedure must be accomplished on two celestial bodies. Their LOS vectors are then computed with respect to the present stable member. These vectors are compared, using the Sighting Data Display Routine (R54) (Figure 7.3.1-2), with vectors obtained either from the LGC star catalog, loaded by the crew, or computed from ephemeris data. Ephemeris data are computed using the Celestial Body Definition Routine (R58) (Figure 7.3.1-3). The comparison is between the actual or stored ephemeris data and the vectors derived from the mark data. Note that R58 is called after taking marks on each celestial body. R54 is called following R58 for the second celestial body.

The difference angle obtained in R54 is displayed to the crew by a flashing VERB 06 NOUN 05. If the angle is within acceptable limits, the astronaut keys PRO and the computer calculates the IMU inertial orientation with respect to the celestial body coordinates, as defined by the two celestial bodies, and stores these data as the present platform orientation (REFSMMAT) for use in future alignments. If the angle is not within limits, the astronaut can key in VERB 32 ENTR (recycle), and return to the flashing VERB 50 NOUN 25 display at the start of P51 (see Table 7.3.1-I), select a celestial body, and start the orientation determination procedure over again.

Recall that, when the program entered R53, the first display (VERB 01 NOUN 71) specified the AOT detent position code and the star code. If the detent position code was 007xx, it would indicate that the COAS would be used for the IMU orientation determination and a flashing VERB 06 NOUN 87 (see Table 7.3.1-I) calling for the optics azimuth and elevation would come up. If the OPT AZ and OPT EL displays that come up in R1 and R2, respectively, are not correct for the optical device being used, the crew can key in VERB 24 ENTR and load the correct azimuth and elevation data.

The computer then computes the X and Y mark plane vectors and the optical axis vector and continues with the orientation determination as with the AOT.

7.3.1.4 Program Alarms

In addition to the anticipated outputs, the program displays a PROG alarm light and stores an alarm code for display at crew discretion. Keying in VERB 05 NOUN 09

allows the program to display an alarm in R1, R2, and R3 (R1 displays the first alarm to occur after the last RSET, R2 the second, and R3 the last). Keying in RSET turns off the alarm light on the DSKY as long as the alarm condition itself has been corrected. Upon clearing the alarm conditions and keying in RSET, keying in KEY REL allows the program to pick up from where it was interrupted. The alarm codes are as follows:

a. Alarm code 00210 is displayed if the IMU is not operating when P51 is entered.
b. Alarm codes 00211 and 00217 are displayed if, at the end of a coarse alignment, the gimbals are not within 2 degrees of the desired value.
c. Alarm code 31211 is displayed when there is an illegal interrupt of an extended verb.
d. Alarm code 31207 is displayed if no vector accumulator (VAC) areas are available for the computation and processing of marks.
e. Alarm code 00111 is displayed if, on a PRO from a NOUN 71 display, a complete pair of marks is not stored in the LGC.
f. Alarm code 00112 is displayed if a mark or a mark reject is not being accepted, or if LGC received ROD input with Average-G off.
g. Alarm code 00113 is displayed if no inbits are available in channel 16, or if ROD switch actuated during mark sequence.
h. Alarm code 00115 is displayed if a mark reject has been attempted with no marks to reject.

If the ISS is not on, alarm 00210 alerts the crew to turn on the IMU and, following a 15-minute warmup of the ISS, reselect P51 by keying in VERB 37 ENTR 51 ENTR.

Upon completion of a coarse-align, if the gimbals are not within 2 degrees of the desired values, alarms 00211 and 00217 alert the crew that a realignment should be made.

If R53 is called while certain extended verb jobs are active there is a possibility that the PROG alarm light will go on, indicating that it is impossible at this time to process marks. Alarm code 31211 is displayed by keying in VERB 05 NOUN 09 If this alarm does occur, a software restart occurs and the whole marking process has to be reinitiated via the calling program. The alarm code displayed could also be 31207, indicating that no VAC areas were available for storing parameters for computations of mark information because the areas were used by previous computations. If this alarm occurs, the computer does an automatic restart, releasing all the VAC areas, and recycles to the beginning of the AOT Mark Routine (R53).

When either the MARK X, MARK Y, or REJECT pushbuttons on the alignment optical telescope has been depressed and R53 has selected the Markrupt Routine (R57), three alarms could occur. The first, alarm code 00113, occurs when there are no in bits in channel 16, to process. This could be either a hardware or software failure, and backup procedures are required to remedy the situation. The next alarm the crew might encounter is alarm code 00112. This alarm will occur when a MARK X, MARK Y, MARK REJECT, or ROD switch action (when Average-G off) occurs under a display other than a MARK VERB display. The DSKY will continue to request the desired astronaut action. The third alarm the crew may encounter is alarm code 00115. This alarm will occur when the MARK REJECT button is depressed when there are no marks to reject.

7.3.1.5 Restrictions and Limitations

The only real restriction in P51 is in the area of proper selection of celestial bodies. For more accurate results in determining the IMU orientation, celestial bodies should be chosen that are at an angle greater than 50 degrees from each other.

7.3.1.6 Program Coordination and Procedures

There is really no best time to perform P51. It is strictly an orientation determination program and is used in cases where it is necessary to calculate a new REFSMMAT. The time to be allowed for the performance of P51, however, depends on two conditions: (1) if the ISS is off and (2) how adept the crew is in sighting and marking on celestial bodies. The first condition requires a warmup period of 15 minutes; the second is variable, depending on the crew.

7.3.1.7 Restarts

P51 is restart-protected.

BLANK

7.3.2 P52, IMU Realign—LGC

The LGC IMU Realign Program performs the same functions of stable member realignment and celestial body sighting calculation as the CMC IMU Realign Program. (Refer to paragraph 7.2.2 for a description of CMC P52.) Any reference to the CSM and CMC can be applied to the LM and LGC. Where they exist, differences between the CSM and the LM IMU Realign Programs arise chiefly from the different optical systems used for star sightings.

The LM crew takes sightings through either the Alignment Optical Telescope (AOT) (a unity-power, 60-deg field-of-view instrument) or the Crew Optical Alignment Sight (COAS) (a backup sighting device). The AOT can be rotated to any one of six fixed viewing positions (detents). Refer to Figure 7.3.2-1. The orientation of each detent relative to the LM body axes is stored in the LGC. Since there are only six discrete AOT viewing positions, a LM attitude maneuver will be necessary if a celestial body is to be centered for marking in one of the optics fields-of-view. For this reason, the LM IMU Realignment Program includes an attitude maneuver subroutine that is automatically entered during the execution of P52 (paragraph 7.3.2.3.6). When the LM is on the lunar surface, IMU orientation determination and realignment are performed by P57, the Lunar Surface Alignment Program.

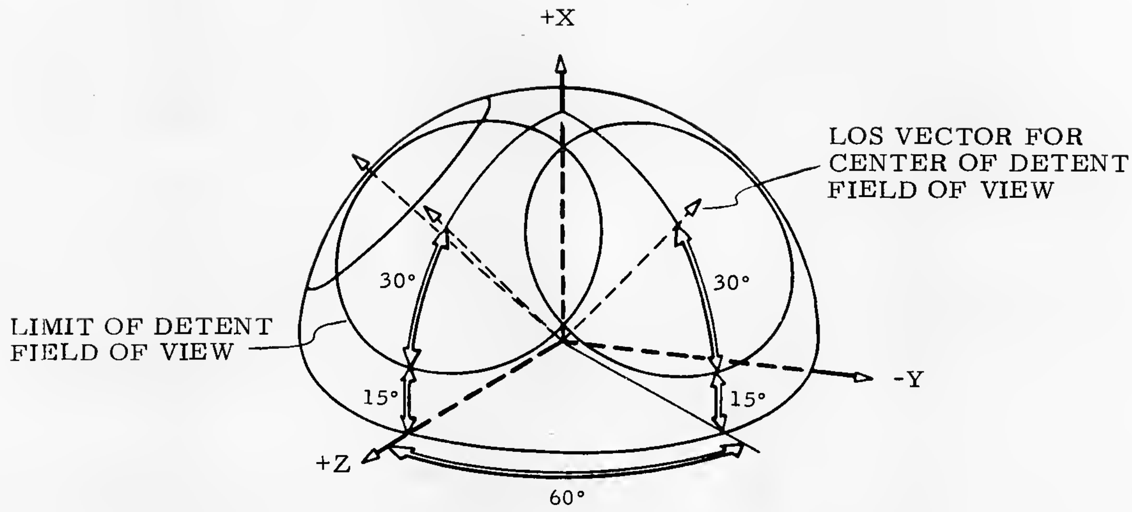
7.3.2.1 IMU Realignment Program Options

The alignment options for the LM P52 are the same as for the CSM P52, paragraph 7.2.2.2. References to the CSM and CMC should, of course, be applied to the LM and LGC. The thrust programs that calculate a preferred orientation relevant to LM alignment are P40, P41, and P42 (the DPS, RCS, and APS thrust programs, paragraphs 6.3.1, 6.3.2, and 6.3.3). (Refer to paragraph 7.2.2.2.1, Preferred Alignment.) In the LM, AOT sightings replace the SXT sightings discussed in paragraph 7.2.2.2.6. The technique of docked LM alignment is discussed in paragraph 7.3.2.5, Program Coordination and Procedures.

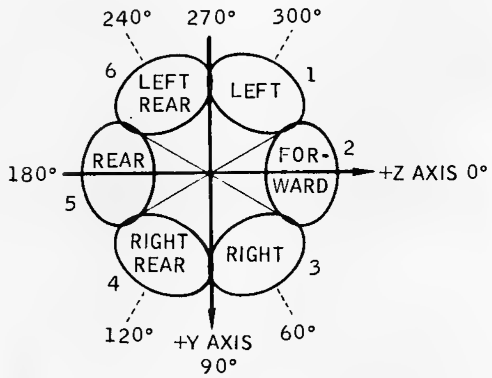
7.3.2.2 Related Routines

The eleven routines listed below are related to the LM IMU Realignment Program. Three of these are called directly by P52; the rest are called by other routines.

- a. IMU Status Check Routine (R02)
- b. Coarse Align Routine (R50)
- c. Inflight Fine Align Routine (R51)



RIGHT, FORWARD, AND LEFT DETENT GEOMETRY



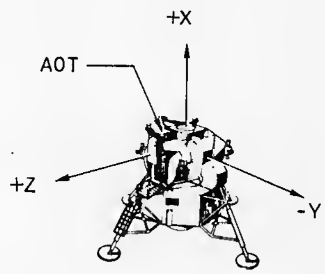


Figure 7.3.2-1. AOT Detent Geometry

d. Auto Optics Positioning Routine (R52)
e. AOT Mark Routine (R53)
f. Sighting Data Display Routine (R54)
g. Gyro Torquing Routine (R55)
h. Markrupt Routine (R57)
i. Celestial Body Definition Routine (R58)
j. Attitude Maneuver Routine (R60)
k. Lunar Surface Sighting Mark Routine (R59)

The first routine called by P52 is the IMU Status Check Routine (R02) which informs the crew if the IMU power is off or if there is no valid REFSMMAT in the LGC. The Coarse Align Routine (R50), also called by P52, calculates the present LM inertial orientation and the gimbal angle changes required to move the stable member into its desired inertial orientation. R50 then positions the stable member to within about 1 deg of the desired orientation.

Next, P52 calls the Inflight Fine Align Routine (R51), which assists the astronaut in selecting two stars suitable for AOT sightings and, in turn, calls several other routines that perform the following:

a. Auto optics positioning (R52)
b. Calculation of observed line-of-sight vectors to a celestial body using AOT mark data (R53 and R57)
c. Retrieval of the corresponding celestial body vector from storage (R58)
d. Display of the difference between stored and measured celestial body angles (R54)
e. Torquing of the gyros into fine alignment with the desired inertial orientation (R55).

Once the stable member has been realigned, R51 offers the astronaut the opportunity to select two more stars and try the marking sequence again. P52 is completed when R51 is completed.

7.3.2.3 LM P52 Flow Description

The following paragraphs discuss the calculation and DSKY activities that occur during P52 (Figure 7.3.2-2); Table 7.3.2-I lists the displays.

7.3.2.3.1 Program Initiation.—The LM crew initiates P52 by keying VERB 37 ENTR 52 ENTR on the DSKY. P52 then calls the IMU Status Check Routine (R02) (Figure 7.3.2-3). R02 tests the REFSMMAT flag; if the flag is set, there is a valid REFSMMAT

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (LM P52) (SHEET 1 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
1	V37 ENTR 52 ENTR	Astronaut	Initiate P52	---	---	---
2	FL V04 N06	P52	Request response to display of alignment option code.	IMU--orientation known R1-- please specify IMU orientation option R2-- option assumed by LGC 00001 = Preferred 00002 = Nominal 00003 = REFSMMAT 00004 = Landing site	R1 00001 checklist R2 oooox R3 Blank	Load desired option. Preferred-PRO to 5 Nominal-PRO to 3 REFSMMAT-PRO to 8 Landing site-PRO to 3
3	FL V06 N34	P52	Request response to display of time of alignment	Nominal or landing site options R1, R2, R3--time of alignment in GET; all zeros indicates present time	R1 00xxx. hr R2 000xx. min R3 0xx.xx sec	Load desired time. Nominal-PRO to 5 Landing site-PRO to 4
4	FL V06 N89	P52	Request response to display of landing site coordinates	Landing site option R1--latitude (+ North) R2--longitude/2 (+ East) R3--landing site altitude	R1 xx.xxx deg R2 xx.xxx deg R3 xxx.xx n.mi.	Load desired coordinates. PRO to 5.

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (LM P52) (SHEET 2 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
5	FL V06 N22	P52	Request response to display gimbal angles after proposed coarse alignment at present spacecraft attitude	All options except REFSMMAT R1-- outer gimbal R2-- inner gimbal R3-- middle gimbal	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg	If near gimbal lock, maneuver, then V32 ENTR to 5. PRO to 6.
6	FL V50 N25	P52	Request crew to perform coarse or fine alignment	Proposed gimbal angles satisfactory	R1 00013 checklist perform coarse align R2 Blank R3 Blank	Normal-PRO to 8, monitor NO ATT and NO DAP lights. Torque-Mode Cont = ATT HOLD; V76 ENTR, monitor NO DAP light ENTR to 7.
7	V16 N20	P52	Monitor current gimbal angles	Astronaut has chosen pulse torque R1-- outer gimbal R2-- inner gimbal R3-- middle gimbal	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg	When torquing complete, go to 25.
8	FL V50 N25	R51	Request celestial body acquisition and specify sighting mark technique (normal inflight X-Y marks or cursor-spiral marks).	Coarse align to new gimbal angles accomplished. Perform celestial body acquisition.	R1 00015 checklist request celestial body acquisition R2 Blank R3 Blank	Maneuver if necessary. LGC star acquisition-PRO to 9. Manual acquisition-ENTR to 9. Cursor-spiral marks—V32 ENTR to 9.

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (LM P52) (SHEET 3 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
9	FL V01 N70	R52 R59	Request response to display of AOT detent and star code for inflight auto-optics maneuver or cursor-spiral star acquisition.	R1--AOT detent code and star code A and B = Zero C = AOT detent D and E = Star Code Key V21 ENTR to reload all codes	R1 ABCDE R2 Blank R3 Blank C = 0-COAS/LPD calibration = 1-front left detent = 2-front center detent = 3-front right detent = 4-rear right detent = 5-rear center detent = 6-rear left detent = 7-backup optical system DE= 00-planet = 01 to 45-star = 46, 47, 50-sun earth, moon	X-Y MARKING PRO to 13 (to 10 if C ≠ 0 or 7; to 11 if DE = 00). To terminate P52, key V34 ENTR. CURSOR-SPIRAL MARKING PRO to 12 (to 11 if DE = 00). Alarm 00404 indicates star not available in any detent. PRO to 14 or V32 ENTR to 9.
10	FL V06 N87	R52	Display and request response to optical system LOS definition.	AOT detent code = zero or 7 R1--the azimuth of the optical system in use. (the angle in the LM Y-Z plane measured	R1 xxx.xx deg R2 xxx.xx deg R3 Blank	Load desired values. PRO to 13 (to 11 if target is planet).

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (LM P52) (SHEET 4 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
				from the LM +Z-axis to the projection of the LOS on the Y-Z plane.) Polarity is positive for negative rotation about the LM +X-axis. R2-- The corresponding LOS elevation. (the angle from the LOS to the LM Y-Z plane.) Polarity is positive for a LOS in the same hemisphere as the LM +X-axis.		
11	FL V06 N88	R58	Display and request response to assumed planet position vector	Celestial body code indicated planet R1-- Xpl = X component of LGC assumed planet unit position vector in Basic Reference coordinates. R2-- same as R1 for Y component R3-- same as R1 for Z component	R1 .xxxxx Xpl R2 .xxxxx Ypl R3 .xxxxx Zpl	X-Y MARKING Load desired values. PRO to 13. CURSOR-SPIRAL PRO to 12.

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (LM P52) (SHEET 5 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
12	FL V06 N79	R59	Request response to display of required cursor and spiral angles and position code.	R1--cursor angle; the angle displayed on AOT readout counter when target is bracketed by cursor. R2--spiral angle; angle when target bracketed by spiral. R3--code for required AOT detent.	R1 xxx.xx deg R2 xxx.xx deg R3 xxxxx	To redefine star, V32 ENTR to 9. PRO to 14.
13	FL V50 N18	R60	Request auto maneuver be performed and display final FDAI ball angles which will result from desired auto maneuver.	If final FDAI angles indicate + or -90 deg yaw, the transformation from IMU to FDAI in roll and pitch is indeterminate and R1 and R2 will indicate zero. For yaw angles near + or -90 deg, the values of R1 and R2 may not be reliable.	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg R1 roll R2 pitch R3 yaw	Auto maneuver-Guid Cont switch to PGNS, Mode Cont switch to PGNS AUTO, PRO. Manual maneuver—Mode Cont to PGNS ATT HOLD, maneuver. Bypass—ENTR to 14 (to 9 if COAS/LPD calibration).
14	FL V01 N71	R53	Request response to display of AOT detent and star code	R1--A, B = 0; C= AOT detent; DE = star code. AOT detent code used for sighting: 1 = front left detent 2 = front center detent	R1 00CDE AOT detent code and star code R2 Blank R3 Blank	Load desired values. X-Y MARKING PRO to 17. If C = 7 to 15 Cursor-Spiral Marking PRO to 18. If DE = 00 to 16.

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (LM P52) (SHEET 6 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
				3 = front right detent 4 = rear right detent 5 = rear center detent 6 = rear left detent 7 = backup optical system Star code: 00--planet 01 to 45--star 46--sun 47--earth 50--moon		
15	FL V06 N87	R53	Display and request response to present optical system LOS definition	R1--optics azimuth R2--optics elevation (see FL V06 N87 of R52 above)	R1 xxx.xx deg R2 xxx.xx deg R3 Blank	Load desired values. PRO to 17.
16	FL V06 N88	R58	Display and request response to assumed planet position vector	See No. 11	R1 .xxxxx Xpl R2 .xxxxx Ypl R3 .xxxxx Zpl	PRO to 18.
17	FL V54 N71	R53	Request astronaut to mark on celestial body, using X and Y MARKS.	(See FL V01 N71 of R53 above.) M = number of X MARKS N = number of Y MARKS S = MARK reject pointer	R1 00CDE R2 S000M R3 S000N	Execute marks. PRO to 9 after 1st target, to 23 after 2nd target. To redefine star, VERB 32 ENTR to 14. If target is planet, PRO will go to 17a. Key ENTR to reverse mark reject.

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (LM P52) (SHEET 7 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
17a	FL V06 N88	R53	Display and request response to planet vector.	See No. 11	R1 .xxxxx Xpl R2 .xxxxx Ypl R3 .xxxxx Zpl	PRO to 9 after 1st target or 23 after 2nd target.
18	FL V52/53 N71	R53	Request mark on body with cursor V52 or spiral V53.	C = detent; DE = star code S = mark reject pointer M = cursor mark counter N = spiral mark counter	R1 00CDE R2 S000M R3 S000N	Depress X or Y MARK button or ROD switch to 19. PRO. If mark data rejected, go to 21. If no mark data rejected and planet code used, to 22. Otherwise, go to 9 for 1st star or to 23 for 2nd star. ENTR to reverse mark verb and mark reject pointer. Change target V32 ENTR to 14.
19	FL V21/22 N79	R57	Request key in of cursor angle V21 or spiral angle V22.	Load request appears when either mark button or ROD switch is depressed in step 18.	R1 xxx.xx deg R2 xxx.xx deg R3 Blank	Load cursor or spiral angle. If cursor/spiral angle not changed from previous load Key VERB PRO. Go to 20.
20	FL V06 N79	R57	Display and request response to cursor or spiral angle data entry.	Display appears when cursor or spiral angle is loaded in step 19.	For cursor data R1 xxx.xx deg R2 Blank R3 Blank For Spiral data R1 Blank R2 xxx.xx deg R3 Blank	Verify cursor or spiral angle. PRO to 18. Load new angle; V21 or V22 ENTR. Mark counter increments by 1.

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (LM P52) (SHEET 8 OF 9)

No.	DSKY	Initiated by	Purpose	Condition	Register	Crew Action
21	FL V50N25	R53	Possible display to request response if mark data rejected by LGC.	Display appears only if the LGC star vector computation rejects mark data. R2 = number of mark data sets rejected	R1 00016 R2 0000R R3 Blank	To continue alignment with average star vector computed from non-rejected mark data, PRO. If planet code used, go to 22. Otherwise, go to 9 for 1st star or to 23 for 2nd star. ENTR to (redo marking) go to it. VERB34 ENTR to terminate.
22	FL V06N88	R58	Display and request response to assumed planet position vector.	DE = 00 in step 18.	R1 .xxxxx Xpl R2 .xxxxx Ypl R3 .xxxxx Zpl	PRO to 9 after 1st target. PRO to 23 after 2nd target.
23	FL V06N05	R54	Request response to display of sighting angle difference.	R1—difference between actual and measured angle between celestial bodies marked.	R1 xxx.xx deg R2 Blank R3 Blank	Reject—V32 ENTR to 25. Accept—PRO to 24.
24	FL V06N93	R55	Display and request response to angles through which each gyro must be torqued to complete fine alignment.	R1 — X gyro R2 — Y gyro R3 — Z gyro	R1 xx.xxx deg R2 xx.xxx deg R3 xx.xxx deg	Torque-V76 ENTR, MODE CONTROL to ATT HOLD, PRO to 25. Bypass torque-V32 ENTR to 25.
25	FL V50N25	P52, R51	Request please perform fine align	R1 —perform fine align	R1 00014 checklist R2 Blank R3 Blank	Third star check—PRO to 8. Exit P52-ENTR, V77 ENTR.

TABLE 7.3.2-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM IMU REALIGNMENT (LM P52) (SHEET 9 OF 9)

DSKY	Initiated By	Purpose	Condition	Register
V05 N09 ENTR	Astronaut	Display alarm codes stored by LGC	Alarm codes displayed as follows: 00111--mark missing 00112--mark or mark reject not accepted 00113--routine called unnecessarily by hardware or software failure 00115--mark reject attempted with no marks to reject 00206--zero encode not allowed with coarse align and gimbal lock 00207--ISS turn-on request not present for 90 sec 00210--IMU not on 00211--coarse align error 00217--bad return from ISS mode switch 00220--IMU on, but no REFSMMAT	R1 xxxxx R2 xxxxx R3 xxxxx
FL V05 N09	R59 R51	Display alarm code	00404--specified star not in AOT field of view 00405--two stars not available	
V05 N09 ENTR	Astronaut	Display alarm code stored by LGC	31207--no VAC available 31211--illegal interrupt of extended verb	

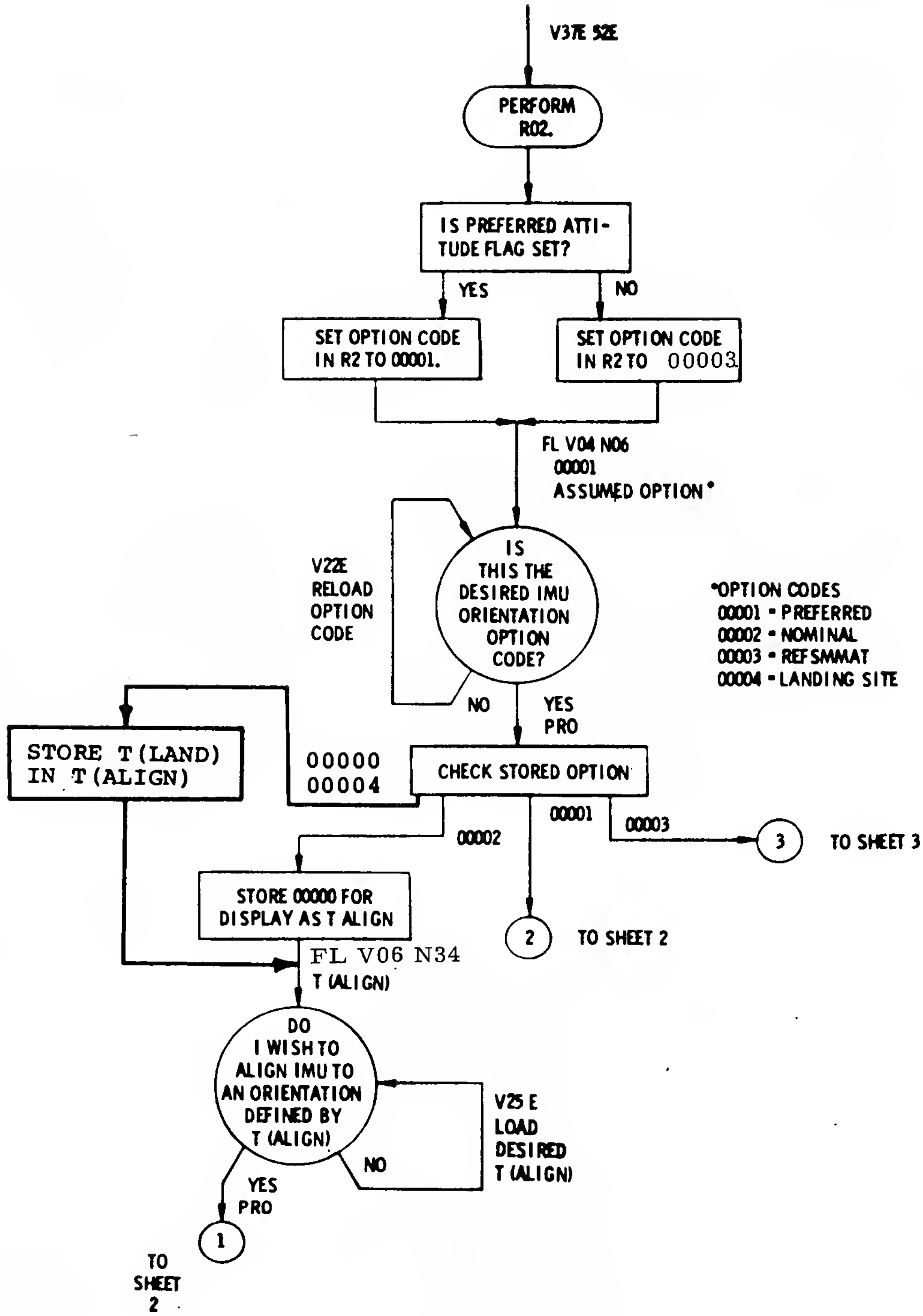


Figure 7.3.2-2. IMU Realign Program (LM P52) (Sheet 1 of 3)

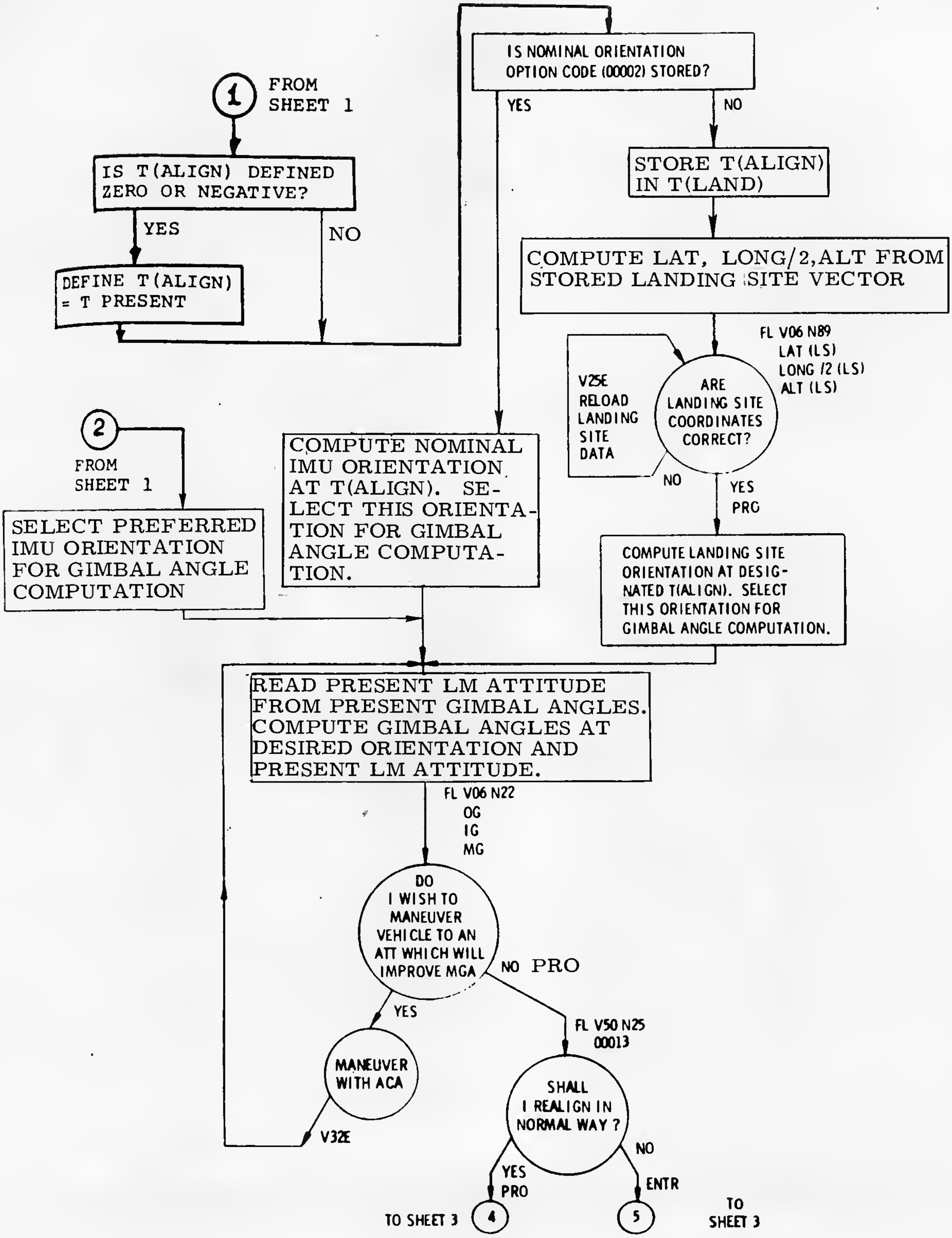


Figure 7.3.2-2. IMU Realign Program (LM P52) (Sheet 2 of 3)

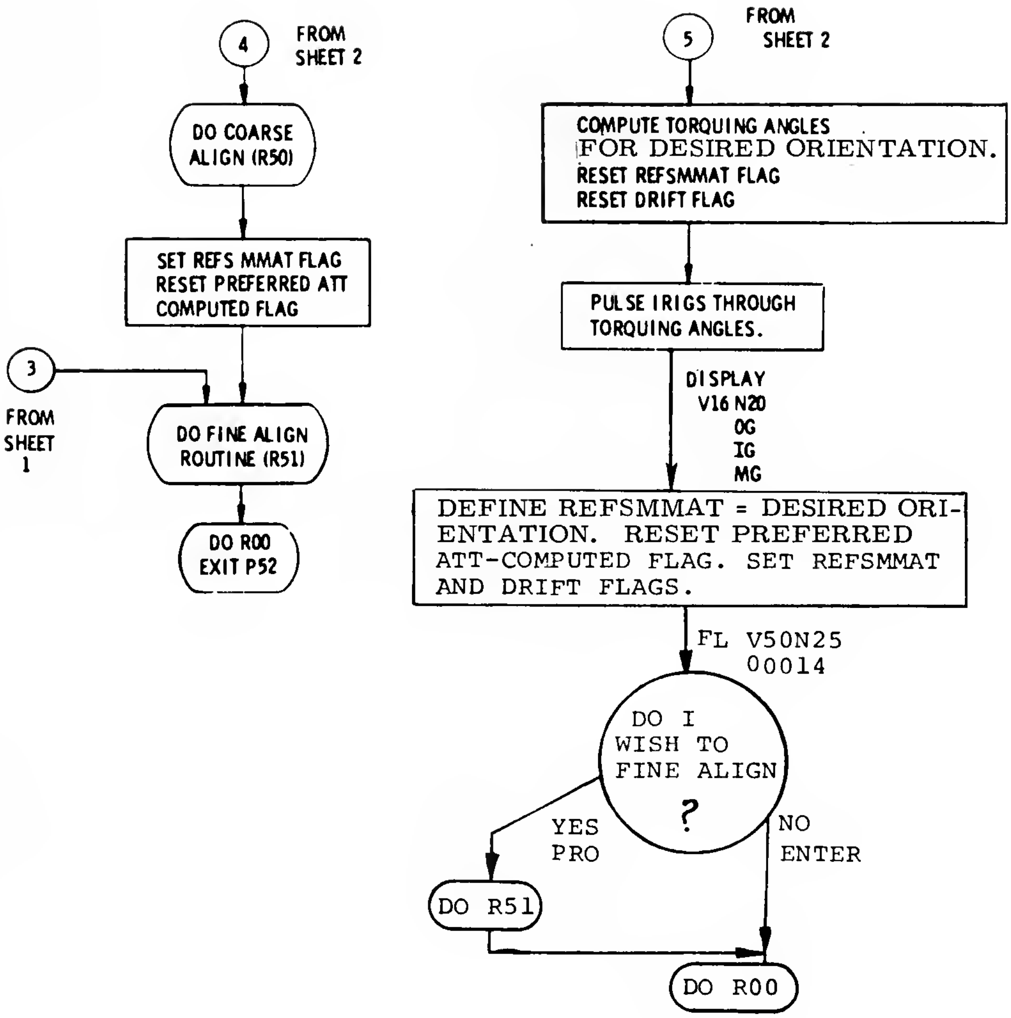


Figure 7.3.2-2. IMU Realign Program (LM P52) (Sheet 3 of 3)

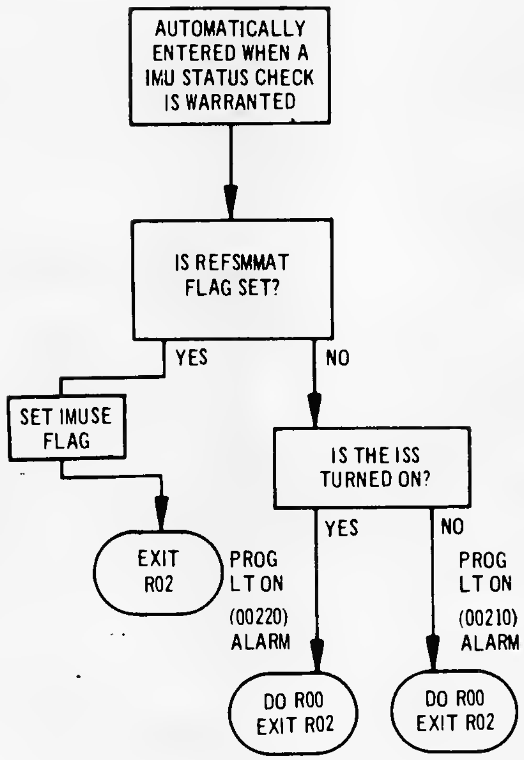


Figure 7.3.2-3. IMU Status Check Routine (LM R02)

in storage and R02 returns control to P52. If the REFSMMAT flag is reset (cleared), R02 illuminates the PROG light. The alarm is verified by keying VERB 05 NOUN 09 ENTR; alarm code 00210 indicates the ISS is not on. Alarm 00220 indicates the ISS is on, but there is no valid REFSMMAT. (If alarms occur here, P52 is automatically terminated. The IMU should be powered up and P51 executed.)

If all is well with the ISS and REFSMMAT, P52 tests the PREFERRED ATTITUDE-COMPUTED flag. If the flag is set, the Preferred alignment option code (00001) is displayed in register R2 as discussed below; if the flag is cleared, the REFSMMAT option code (00003) is displayed.

The first display the astronaut sees in P52 is a flashing VERB 04 NOUN 06, with R1 containing 00001 ("Please specify IMU orientation option") and R2 containing the alignment option code assumed by the LGC. The astronaut can key VERB 22 ENTR to reload the desired code in R2, or can approve the option displayed by keying PRO. (The four option codes are: 00001—preferred; 00002—nominal; 00003—REFSMMAT; 00004—landing site.)

P52 now proceeds to one of three activities, depending on the alignment option chosen: (a) if the REFSMMAT option was chosen, coarse alignment is bypassed and P52 calls the Fine Align Routine, R51 (see paragraph 7.3.2.3.4); (b) if the preferred option was chosen, P52 now carries out the coarse align gimbal angle computations of paragraph 7.3.2.3.2; (c) if the nominal or landing site option was chosen, P52 needs more information before it can coarse align the gimbals and requests it by the displays described below.

In the nominal or landing site option, the astronaut sees a flashing VERB 06 NOUN 34, with the time of alignment displayed in hours, minutes, and seconds (GET). If the nominal option was chosen, the display is all zeros, indicating the computer chose the present time as the time of alignment. If the landing site option was chosen, the DSKY registers show the time of lunar landing as the selected time of alignment. The astronaut can correct the time by keying VERB 25 ENTR and loading the desired time or can proceed with the time displayed by keying PRO.*

*The stored landing site coordinates can be modified only by prelaunch erasable load, P27, P57, or P68. If the crew corrects VERB 06 NOUN 89 in P52, the newly defined landing site will be effective only to define an orientation for the stable member.

If the nominal option was chosen, P52 calculates the desired stable member inertial orientation based on the LM state vector at the time of alignment and executes the gimbal angle computations given in paragraph 7.3.2.3.2. The landing site option of P52 must know the lunar landing site coordinates before it can realign the stable member. Accordingly, P52 displays the landing site coordinates, which the computer has in storage, by flashing VERB 06 NOUN 89. R1, R2, and R3 contain the landing site latitude, half-longitude, and altitude, respectively. The astronaut can load new numbers and, when satisfied with the data, continue into the gimbal angle computations below by keying PRO.

7.3.2.3.2 Gimbal Angle Computation.—For the preferred, nominal, or landing site option, the program now reads the current LM attitude from the gimbal angles and uses this information to determine the gimbal angles for the desired stable member alignment at the present LM attitude. P52 flashes VERB 06 NOUN 22 and displays the calculated outer, inner, and middle gimbal angles. If there is a risk that the stable member will be positioned into gimbal lock (middle gimbal angle of 85 deg or more), the astronaut can maneuver the LM with the attitude control assembly (ACA) and recycle to update the displayed gimbal angles by keying VERB 32 ENTR. When the displayed angles appear satisfactory, the astronaut keys PRO.

P52 next flashes VERB 50 NOUN 25. R1 contains checklist code 00013 ("Please perform normal or gyro torque coarse align"). The astronaut must now choose one of two responses: (1) pulse torque coarse alignment (ISS in fine align mode), or (2) normal coarse alignment (ISS in coarse align mode).

If the astronaut intends to have the stable member pulse torqued to the desired orientation and if he does not want the DAP to maneuver the LM to follow the stable member during pulse torquing, he must command the minimum impulse mode. He keys VERB 76 ENTR with the Mode Control switch set to ATT HOLD. This sets the PULSES flag. The DAP now responds only to ACA inputs.* Another ENTR commands P52 to compute the torquing angles required to achieve the new IMU orientation and to pulse the gyros through the torquing angles. Before torquing starts, P52 resets the REFSMMAT flag. While torquing is in progress, P52 displays VERB 16 NOUN 20 and the current outer, inner, and middle gimbal angles. When torquing is accomplished, P52 puts the desired IMU orientation into REFSMMAT and sets the REFSMMAT flag. The DSKY next flashes VERB 50 NOUN 25, with R1

*To return to Rate Command and ATT HOLD modes, the astronaut must key VERB 77 ENTR.

containing chcklist code 00014 ("Please perform fine align"). If the astronaut wants to carry out AOT sightings, he keys PRO. P52 then calls R51, the Inflight Fine Align Routine (paragraph 7.3.2.3.4). If no AOT sightings are desired and the astronaut keys ENTR, P52 is terminated.

The alternate crew response to "Please perform normal or gyro torque coarse align" is to key PRO. P52 will then call the Coarse Align Routine (R50) (paragraph 7.3.2.3.3). After calling R50, P52 calls R51, the Inflight Fine Align Routine.

7.3.2.3.3 Coarse Align Routine.—When the Coarse Align Routine (R50) (Figure 7.3.2-4) is called, it computes the gimbal angles at the desired stable member orientation and present LM attitude. If no required gimbal angle change is greater than one deg, the desired stable member orientation is put into REFSMMAT, and R50 returns control to P52. For larger required gimbal angle changes, the LGC commands the ISS to the coarse align mode, turns on the NO ATT light, disables the DAP, and repositions the stable member. (Alarm codes 00211 and 00217 will be stored at this time if there is a 2-deg error between the actual and commanded gimbal angles.) The LGC then terminates the coarse align ISS mode and enables the DAP to resume LM attitude hold. The NO ATT light is then turned off by the LGC. R50 then defines REFSMMAT to be the desired stable member orientation.

When R50 is completed, it returns control to P52, which sets the REFSMMAT flag and resets the PREFERRED ATTITUDE-COMPUTED flag, informing other programs that there is a valid REFSMMAT but no preferred attitude in storage. P52 then calls R51, the Inflight Fine Align Routine (Figure 7.3.2-5), to manage celestial body acquisition, AOT marktaking, and pulse torque fine alignment.

7.3.2.3.4 Inflight Fine Align Routine.—R51 flashes VERB 50 NOUN 25, with checklist code 00015 in R1 ("Please perform celestial body acquisition"). If the astronaut decides to use cursor spiral measurements for the inflight IMU alignment, he keys in VERB 32 ENTR. This action sets a flag which causes the program to branch to the Lunar Surface Sighting Mark routine (R59) (paragraph 7.3.3.4.4). After performing R59 the program logic returns to the Sighting Data Display Routine (R54) in R51 (paragraph 7.3.2.3.10). If the astronaut wants the computer to pick a pair of stars for X-Y sightings, he keys PRO. The computer then searches its star catalog to find a usable pair of stars. The LGC considers only the forward center detent and tests for two stars that meet the following criteria:

a. Both stars are within 50 deg of the center of the field of view.
b. The angle of separation of the pair is at least 50 deg.
c. The stars are not obscured by the sun, earth, or moon.

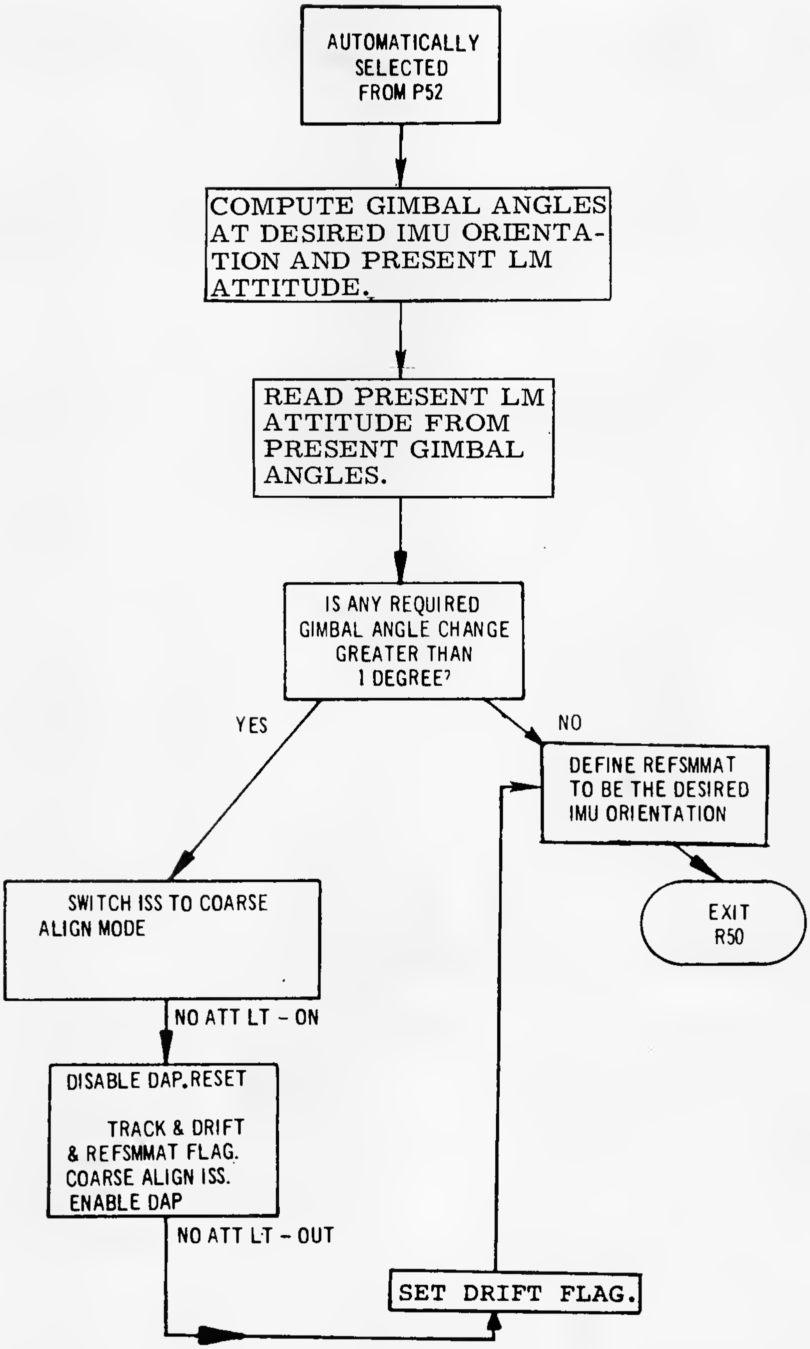


Figure 7.3.2-4. Coarse-align Routine (LM R50)

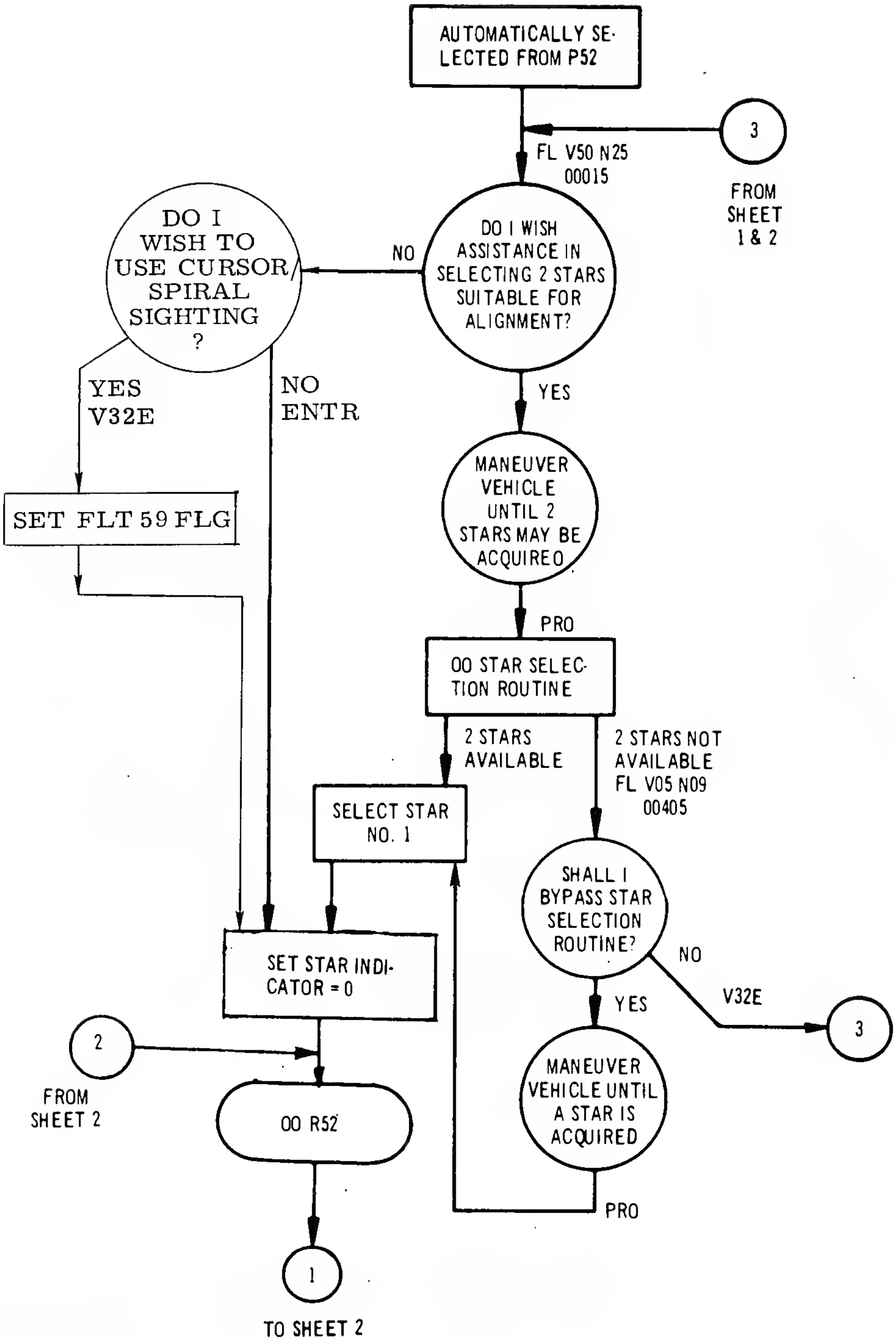


Figure 7. 3. 2-5. Inflight Fine-align Routine (LM R51) (Sheet 1 of 2)

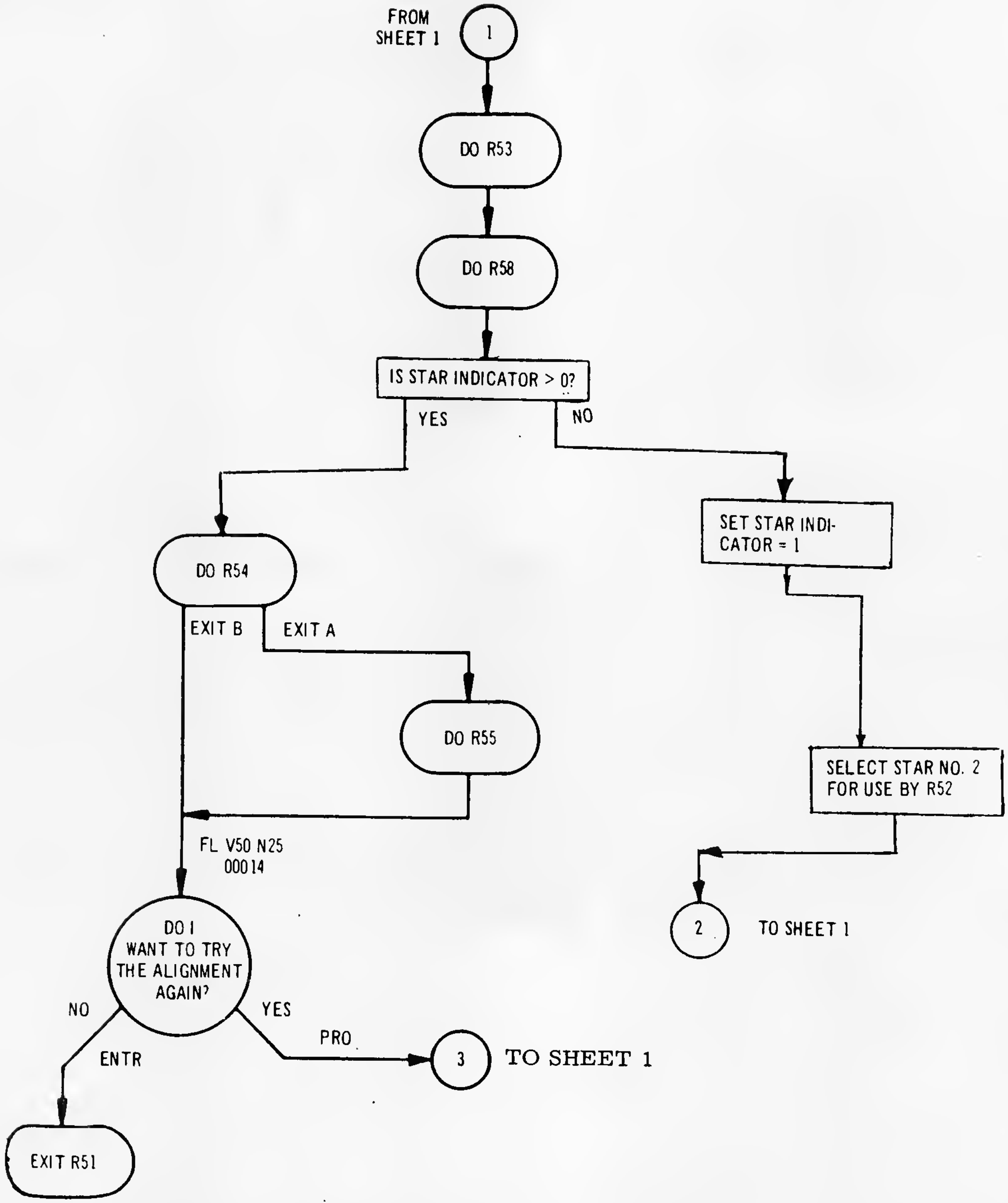


Figure 7.3.2-5. Inflight Fine-align Routine (LM R51) (Sheet 2 of 2)

If there is more than one pair that is satisfactory, the pair with the largest separation is automatically chosen for sightings. If a pair is not available at the present LM attitude, the LGC displays alarm code 00405. The astronaut can either (1) reorient the LM and recycle (by VERB 32 ENTR) to the beginning of R51, or (2) maneuver until he acquires a suitable celestial body himself and then key PRO, calling the Auto Optics Positioning Routine, R52 (paragraph 7.3.2.3.5). If the computer was successful in finding a pair of stars for sightings, it selects one star from the pair as a target for the Auto Optics Positioning Routine.

If the astronaut wants to find a pair of celestial bodies without the aid of the computer, he keys ENTR when the computer requests "Please perform celestial body acquisition." R51 then immediately calls the Auto Optics Positioning Routine, R52 (Figure 7.3.2-6).

7.3.2.3.5 Auto Optics Positioning Routine.—The purpose of R52 is to point the line of sight (LOS) of any AOT detent at a specified celestial body by maneuvering the LM. R52 flashes VERB 01 NOUN 70 and displays the AOT detent and target celestial body codes in R1. (See Table 7.3.2-I.) If the astronaut wants to change these numbers, he can do so now by keying VERB 21 ENTR and loading the desired codes. When the codes are correct and the astronaut wants to go ahead with auto optics positioning, he keys PRO. (A VERB 34 ENTR terminates P52.) R52 then resets the 3-AXIS flag, which is tested later by the Attitude Maneuver Routine, R60. If the astronaut has approved an AOT detent code of 0 or 7 (COAS/LPD calibration or COAS sighting, respectively), he sees flashing VERB 06 NOUN 87 with the azimuth and elevation of the present optics LOS displayed in R1 and R2. VERB 24 ENTR is used to correct these numbers, if desired; PRO is used to approve the displayed values.

For any AOT detent code, the LGC now computes the LOS vector as specified by the preceding displays and calls the Celestial Body Definition Routine (R58) for the intended target. If the target is a star, R58 obtains its Basic Reference vector from the computer's stored ephemeris; if the target is the sun, earth, or moon, R58 calculates the celestial body vector. If the celestial body code of VERB 01 NOUN 70 above was zero (planet or other target), R58 flashes VERB 06 NOUN 88, with the X, Y, and Z components of the planet unit position vector. If these numbers are correct, the astronaut keys PRO; he can change them by keying VERB 25 ENTR followed by the correct components. R58 then returns control to R52.

At this time, R52 defines the LOS to the target celestial body as the direction in which the Attitude Maneuver Routine, R60 (Figure 7.3.2-7), will point the previously selected optics LOS. R52 then calls R60.

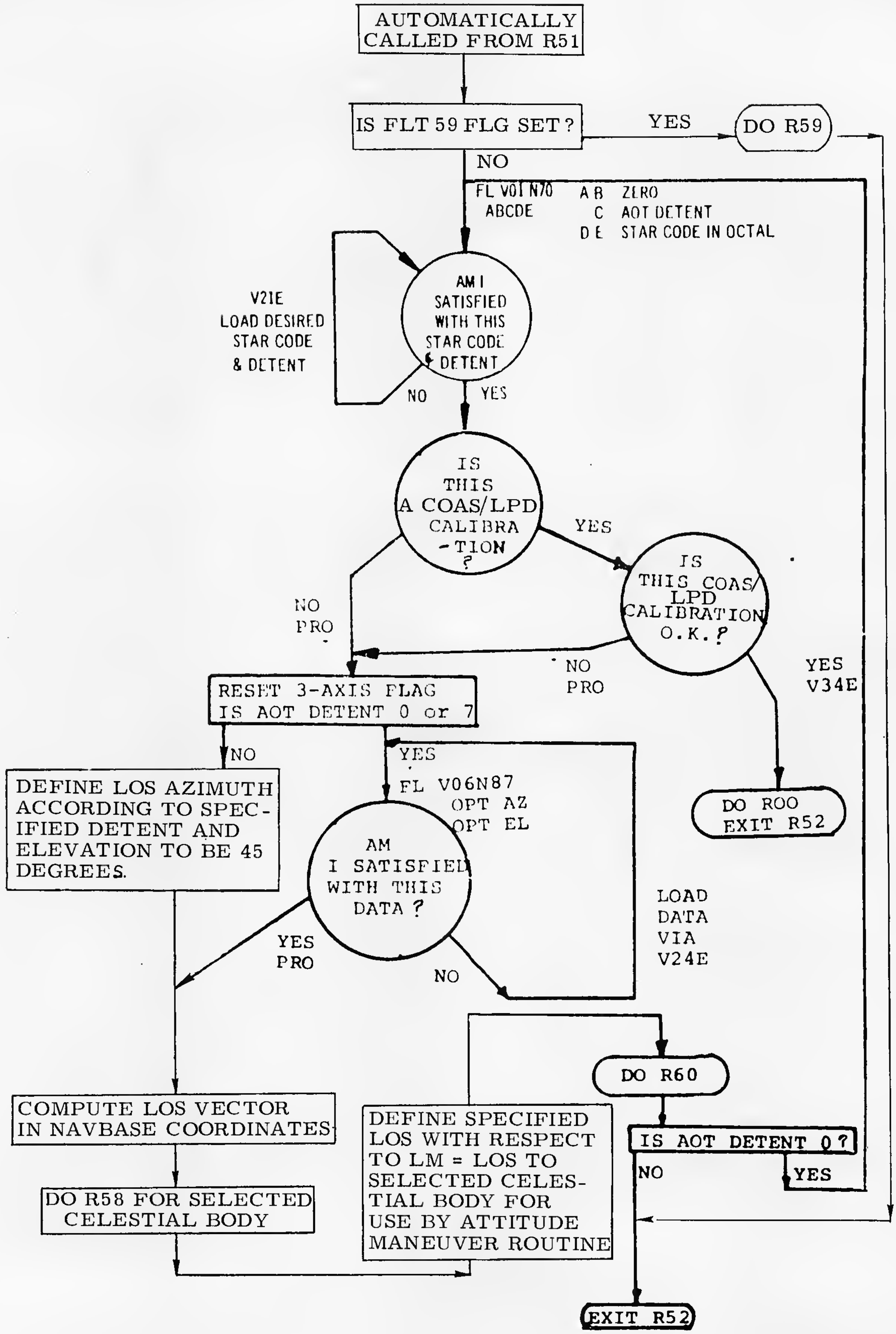


Figure 7.3.2-6. Automatic Optics-positioning Routine (LM R52)

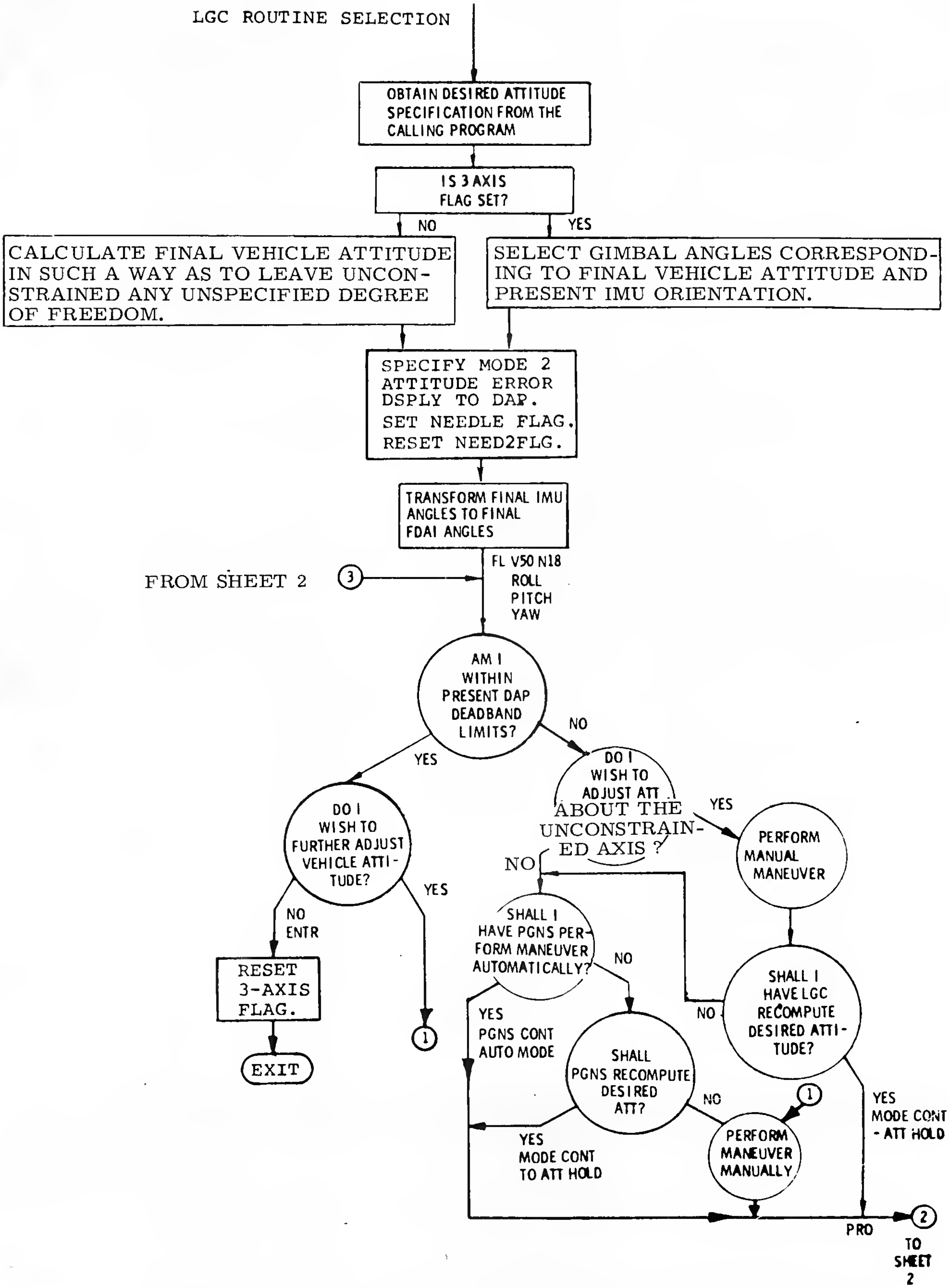


Figure 7.3.2-7. Attitude-maneuver Routine (LM R60) (Sheet 1 of 2)

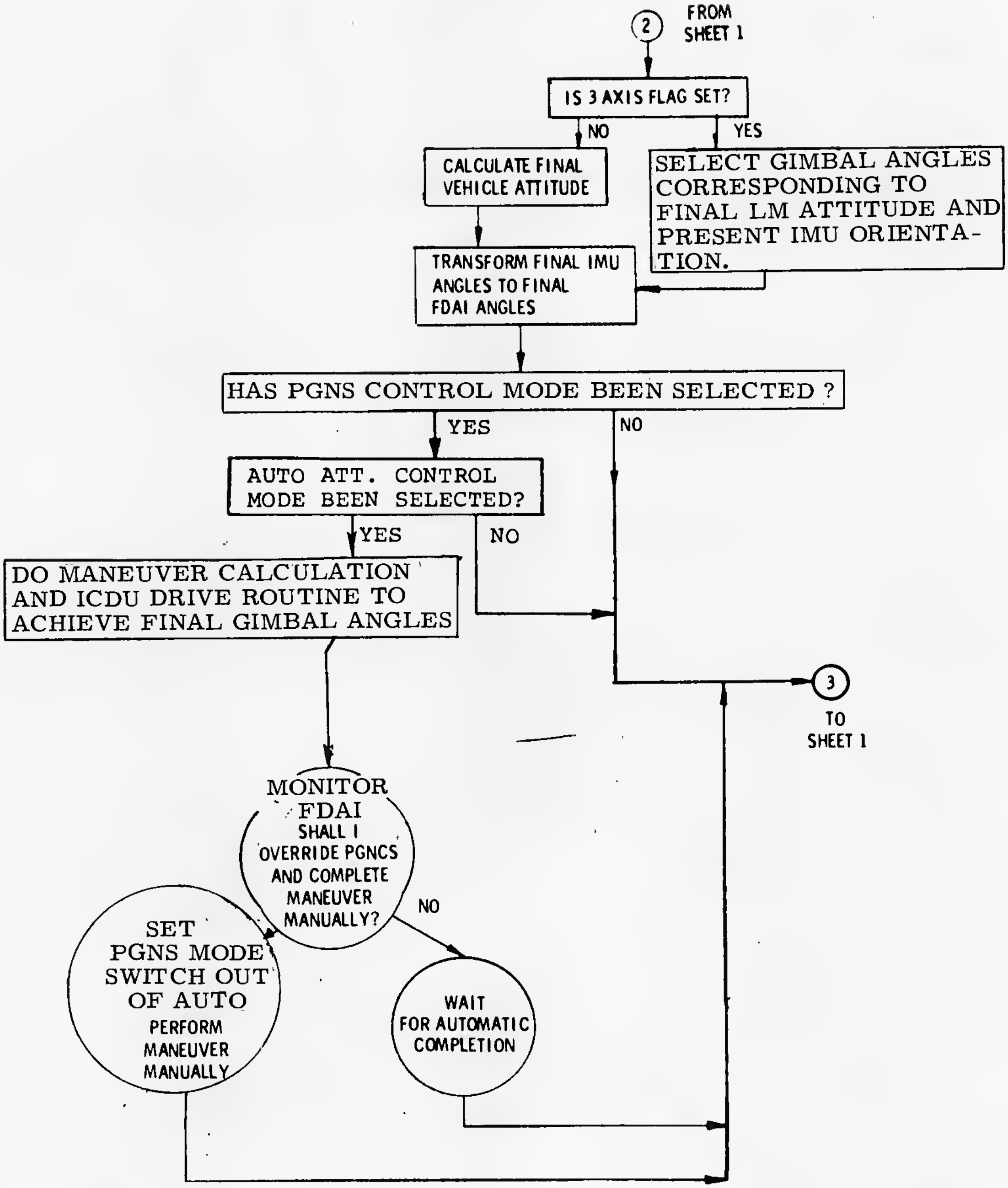


Figure 7.3.2-7. Attitude-maneuver Routine (LM R60) (Sheet 2 of 2)

7.3.2.3.6 Attitude Maneuver Routine.—The purpose of R60 is to maneuver the LM to point a specific body-fixed vector, such as the center of the AOT field of view for a specified detent, along a specified direction in space. This direction is calculated and stored by the calling program. R60 tests the 3-AXIS flag at this time. Since it has been reset by R52, R60 calculates the final LM attitude and gimbal angles required to meet the LOS specifications in such a way as to conserve RCS fuel and not constrain any unspecified degree of freedom. (The alternative for R60, if the 3-AXIS flag is set, is to orient all three LM body axes in specified directions.)

The Attitude Maneuver Routine then flashes VERB 50 NOUN 18 ("Please perform auto maneuver") with the FDAI angles resulting from the proposed maneuver displayed in R1, R2, and R3 as roll, pitch, and yaw, respectively. There are three responses to this display:

a. Auto maneuver—the astronaut sets the Guidance Control switch to PGNS, the PGNS Mode Control switch to AUTO and keys PRO. The LGC then calculates the required final vehicle attitude (using the routine VEC-POINT) and fires the RCS jets to attain the required attitude. If the PGNS Mode switch is set out of AUTO, the maneuver will be terminated immediately. Following astronaut or LGC termination of the maneuver, the computer again flashes VERB 50 NOUN 18 and the desired FDAI angles. The astronaut can now perform another auto maneuver, manual maneuver, or bypass the maneuver.
b. Manual maneuver—the astronaut sets the PGNS Mode Control switch to ATT HOLD and acquires the target using the ACA and FDAI. When the target is acquired, he keys PRO and again sees flashing VERB 50 NOUN 18 and the desired FDAI angles.
c. Bypass the requested maneuver—the astronaut keys ENTR when the DSKY flashes VERB 50 NOUN 18 and the desired ball angles after a successful auto or manual star acquisition maneuver.

At this point, R52 tests the AOT detent code selected earlier. If it is zero (COAS/LPD calibration), R52 again flashes VERB 01 NOUN 70 and displays the AOT detent and celestial body codes. (Refer to paragraph 7.3.2.3.5.) A VERB 34 ENTR response to VERB 01 NOUN 70 terminates R52 and P52. If the AOT detent code is not zero, R52 is terminated and control returns to R51. (By now, the astronaut should have acquired the celestial body in the AOT, and the next step is to take marks.)

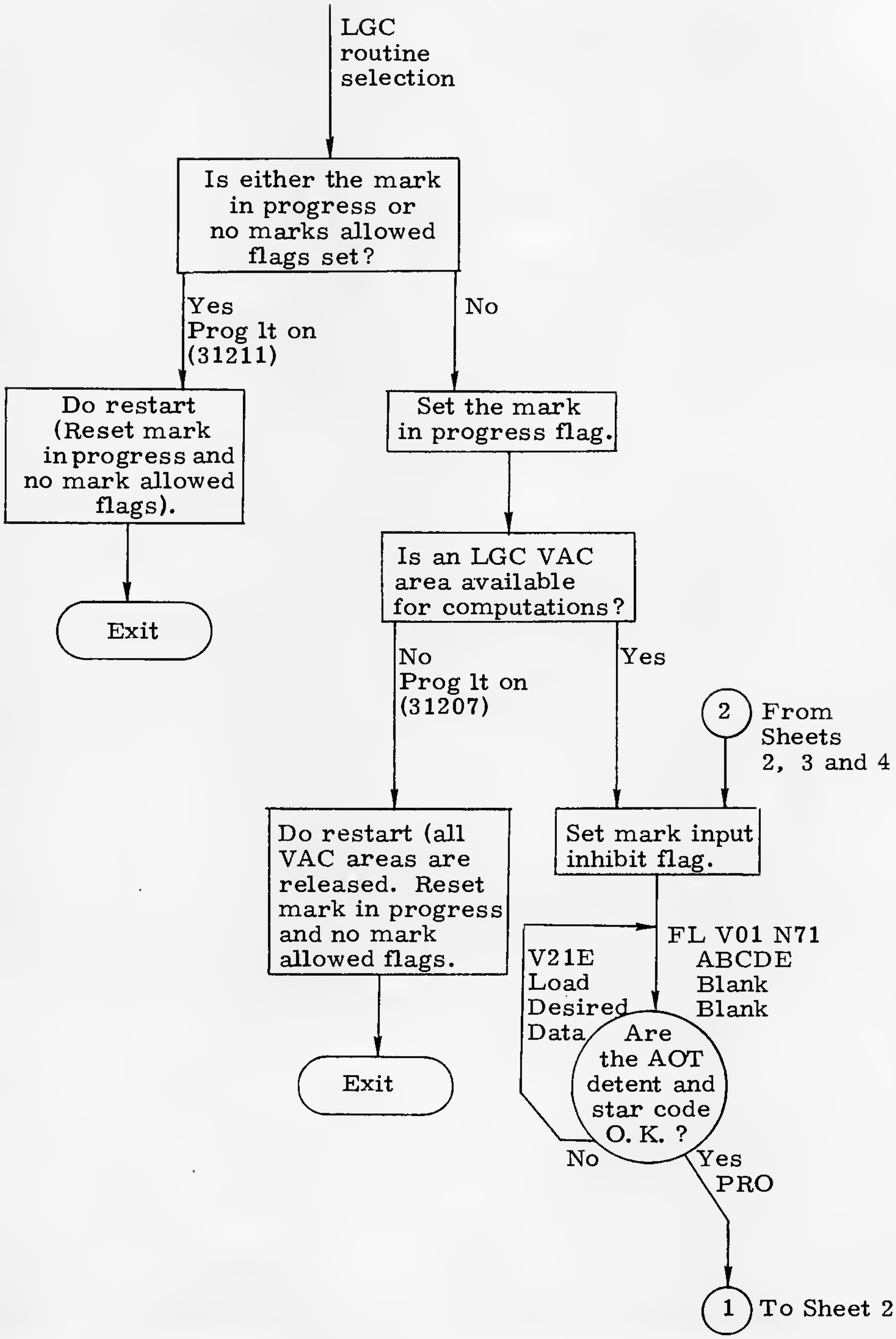


Figure 7.3.2-8. Sighting Mark Routine (LM R53) (Sheet 1 of 4)

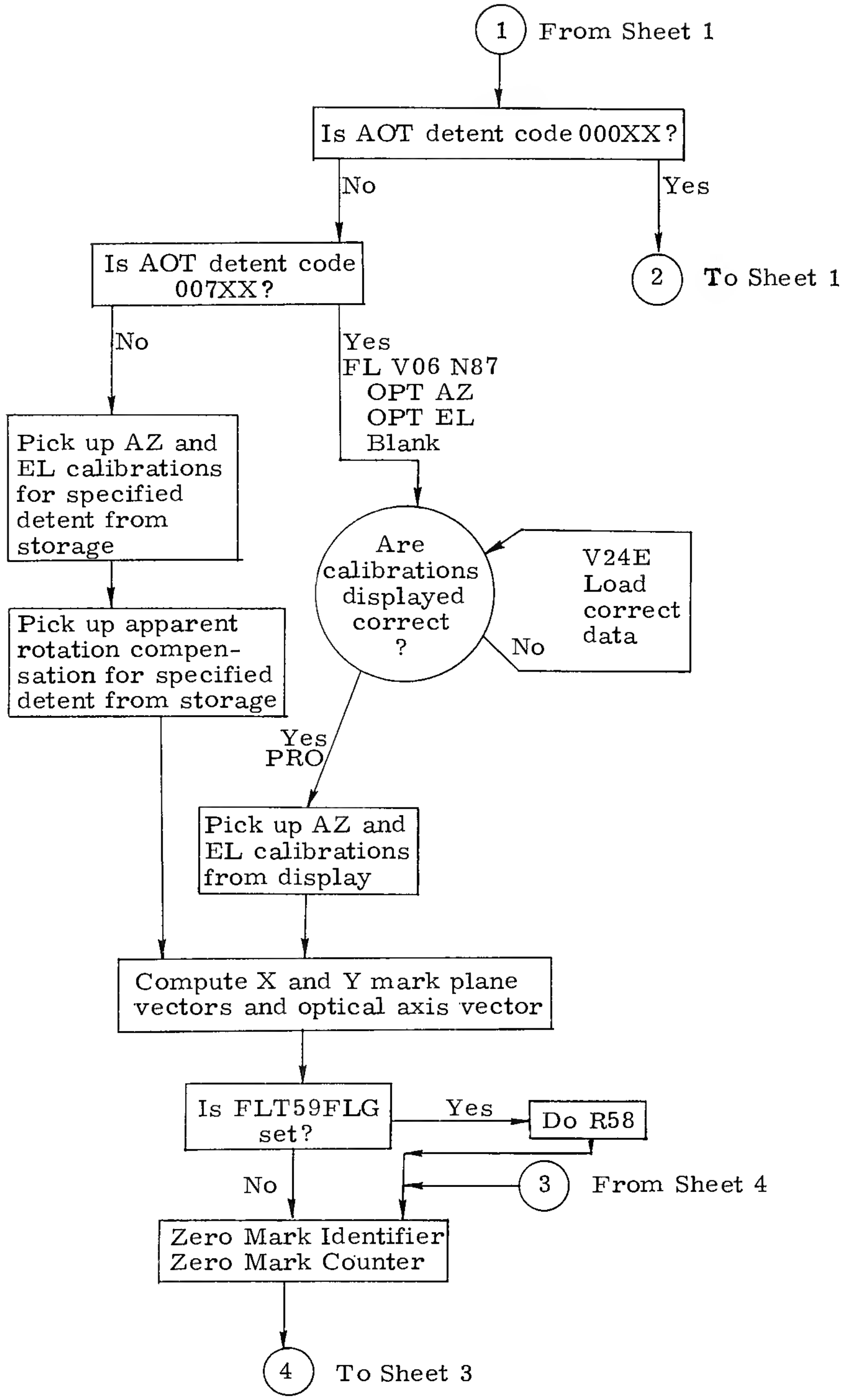


Figure 7.3.2-8. Sighting Mark Routine (LM R53) (Sheet 2 of 4)

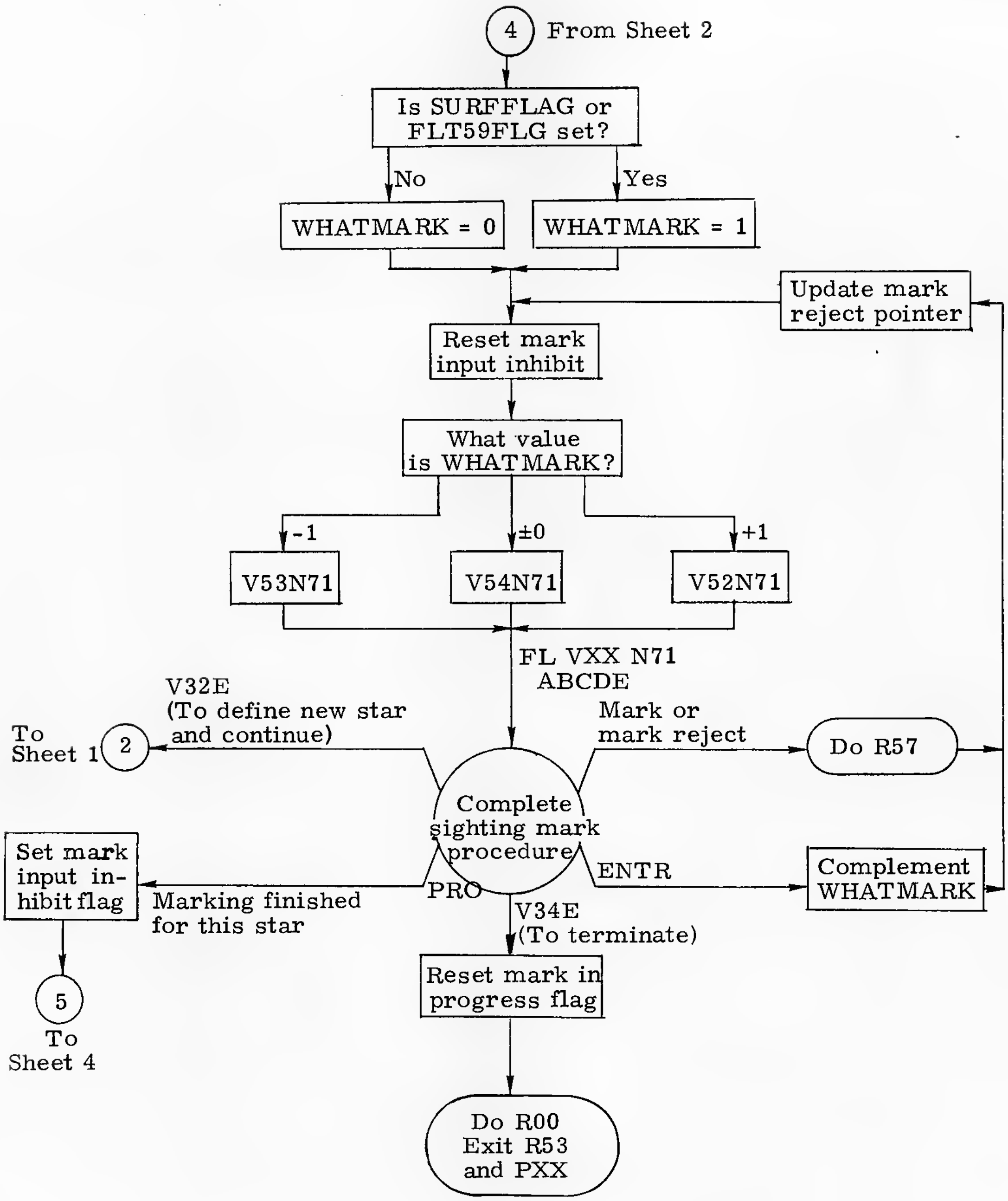


Figure 7.3.2-8. Sighting Mark Routine (LM R53) (Sheet 3 of 4)

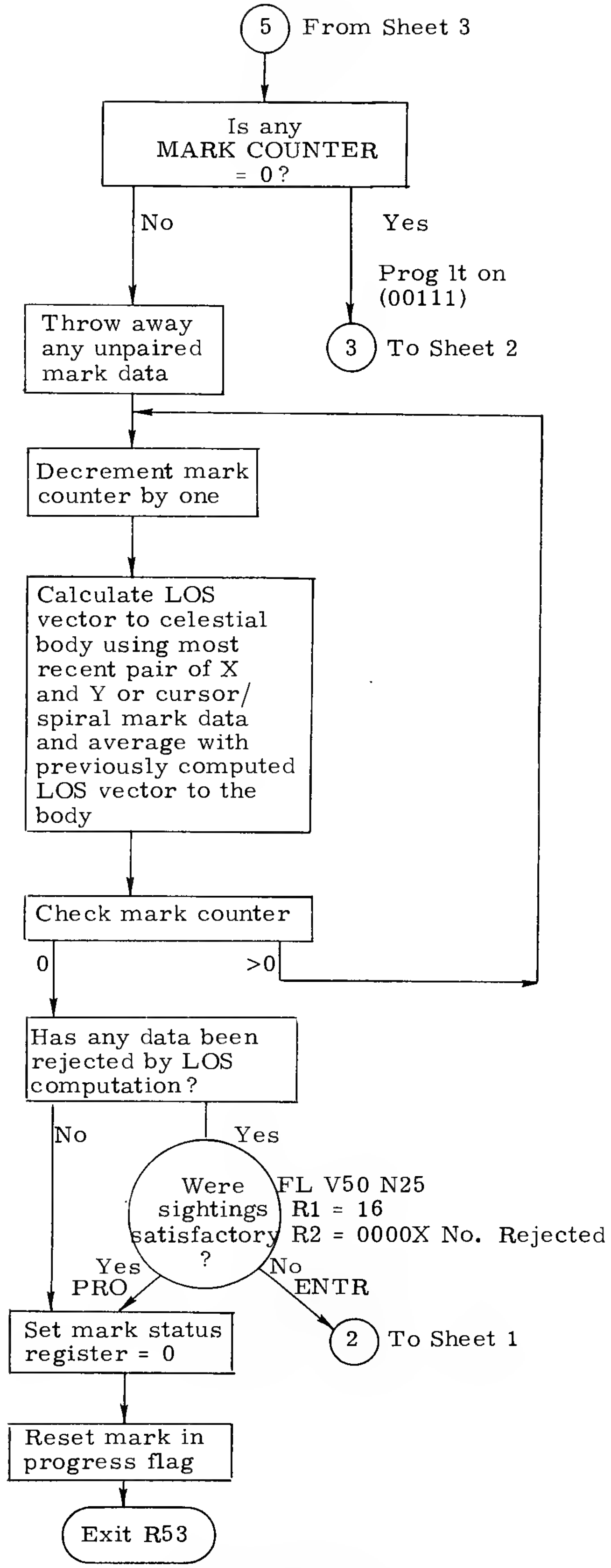


Figure 7.3.2-8. Sighting Mark Routine (LM R53) (Sheet 4 of 4)

7.3.2.3.7 AOT Mark Routine.—R51 now calls the AOT Mark Routine, R53 (Figure 7.3.2-8). R53 requests and processes sighting marks on the two targets. When R53 is initiated, the possible program alarms that may occur are 31211 (illegal interrupt of extended verb); or 31207 (no LGC VAC area available for computations) (Table 7.3.2-I). If no alarms occur, R53 sets the MARK INPUT INHIBIT flag and flashes VERB 01 NOUN 71, with the AOT detent and star codes displayed in R1. VERB 21 ENTR followed by the desired code corrects the values displayed; PRO indicates the astronaut accepts the code values displayed. If the detent code is seven (COAS sighting), R53 flashes VERB 06 NOUN 87, with the stored values for the azimuth and elevation of the backup optics LOS displayed in R1 and R2. These values can be approved by keying PRO or reloaded after keying VERB 24 ENTR. The LGC is then able to calculate the backup optics LOS vector in Navigation Base coordinates. For either AOT or backup optics sightings, R53 computes the orientation of the planes defined by the X- and Y-reticle lines and the optic axis vector. The Sighting Mark Routine then flashes VERB 54 NOUN 71 ("Please mark X- or Y-reticle line-star intersection"). R1 again contains the AOT detent and star codes. X and Y mark counts maintained in R2 and R3 are initially zero.

When the astronaut prepares to take a sighting, he should be sure that the AOT reticle rotation angle is set to zero to ensure that the X- and Y-reticle lines define the proper planes for the LGC LOS vector computations. (The greatest accuracy will result if the marks are taken with the star as close as possible to the field-of-view center.)

A mark is then made by (1) maneuvering the LM such that the target body crosses the X or Y reticle line, and (2) depressing the appropriate mark pushbutton. The astronaut may make up to 5 X and 5 Y marks in any sequence. The mark counters in registers R2 and R3 maintain a count of the accumulated X and Y marks. If more than 5 marks are made, the gimbal angles stored by the fifth mark will be overwritten by the sixth mark. The mark counter will remain at 5. A pointer was added to the mark counter registers so the astronaut will always be aware of what his last mark was. This was primarily for MARK REJECT purposes because the last mark will be rejected first. This pointer is a 1 added to the high digit of mark counter register of the mark just performed. An example: if the astronaut had made two Y marks and had just performed the fourth X mark, the display would be:

VERB 54 NOUN 71

R1 00CDE
R2 10004
R3 00002

The reject pointer indicates that an X mark was made and will be rejected with a MARK REJECT action. If that were the case R2 would be 10003 and further reject action would reduce the R2 counter to 10000 and cause ALARM 115 when there were no more X marks to be rejected. To give the astronaut some control of the reject action, a switch was provided with the ENTR button. Depressing the ENTR button changes the reject pointer to the opposite mark counter. An example: if the astronaut wanted to reject a Y mark in the above display, he would first depress the ENTR button to display:

<u>VERB 54 NOUN 71</u>

R1 00CDE
R2 00004
R3 10002

The reject action would now cause R3 to be 10001.

During inflight alignments, the position of the reject pointer in no way affects any sequence of marking that the astronaut may wish to make. The astronaut can at any time during the marking procedure reject all accumulated mark data by keying VERB 32 ENTR on the mark display. This action causes VERB 01 NOUN 71 of R53 to be displayed to redefine the detent and/or celestial body code and repeat the marking process.

7.3.2.3.8 <u>MARKRUPT Routine.</u>—The MARKRUPT Routine is called by depressing a MARK or MARK REJECT pushbutton. This routine reads and stores the present values of the IMU gimbal angles and the mark time. It also maintains the X and Y mark counter and processes any MARK REJECT action. It also processes mark interrupts from the ROD switch. The ROD switch is used as a backup mark button during cursor-spiral sightings. Alarm 00112 will result if the MARKRUPT Routine is called on a display other than a mark-request display.

When the astronaut is satisfied with the number and quality of marks he has taken, he keys PRO. This returns program control to R53, which sets the MARK INPUT INHIBIT flag to prevent additional marks from being incorporated. R53 then calculates the measured LOS vector to the target using the averaged X and Y mark data and returns control to R51, the Inflight Fine Align Routine.

7.3.2.3.9 <u>Celestial Body Definition Routine.</u>—R51 now calls the Celestial Body Definition Routine, R58 (Figure 7.3.2-10). The purpose of R58 is to obtain, either

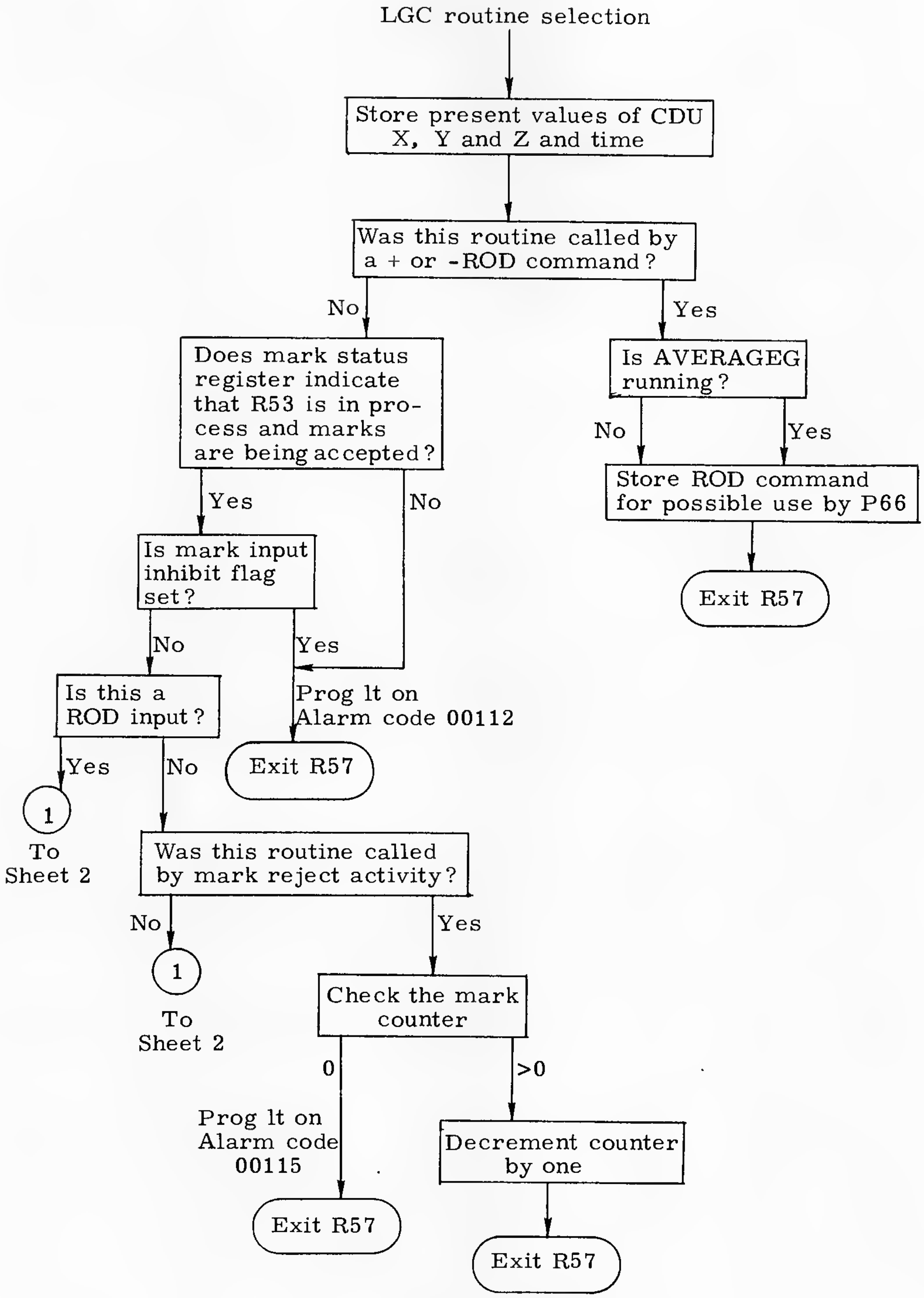


Figure 7.3.2-9. MARKRUPT Routine (LMR57) (Sheet 1 of 3)

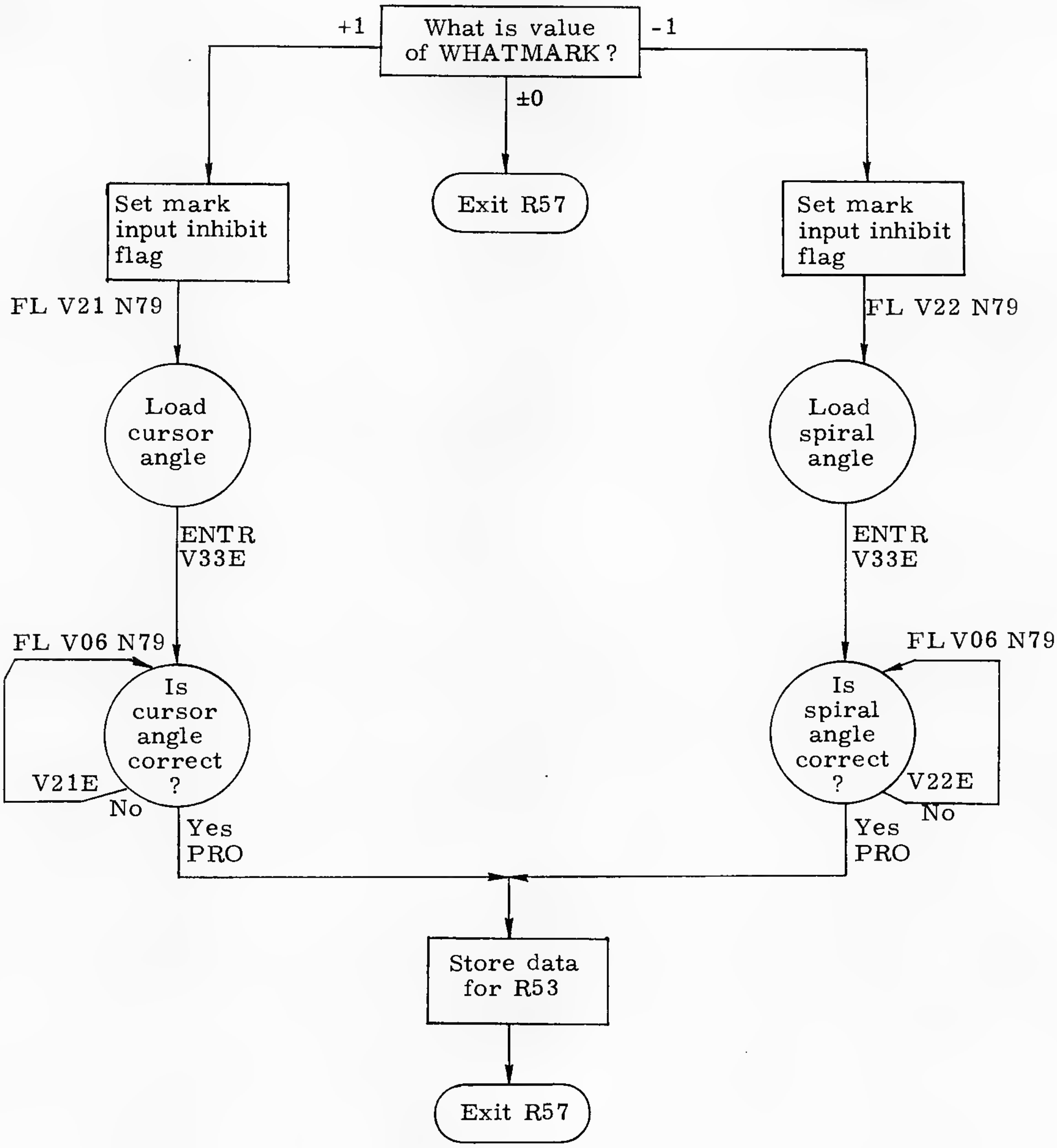


Figure 7.3.2-9. MARKRUPT Routine (LMR57) (Sheet 3 of 3)

from storage, calculation, or crew input, the actual (not AOT-measured) celestial body vector in Basic Reference Coordinates. (The actual and measured vectors are compared later in the Sighting Data Display Routine.) R58 first checks the value of the stored target identification code as follows:

a. If the code is zero (planet or other celestial body), the crew sees a flashing VERB 06 NOUN 88 with the LGC assumed planet position vector components displayed in R1, R2, and R3. Corrected components can be loaded via VERB 25 ENTR or approved by keying PRO. Control is then returned to R51.
b. If the target identification code is 46 (sun), 47 (earth), or 50 (moon), R58 calculates the appropriate celestial body vector based on the LGC's stored ephemerides and returns to R51.
c. If the target is a star, the celestial body vector is obtained directly from storage. R58 is then completed and R51 again takes over.

R51 now calls the Auto Optics Positioning Routine (R52) for the second time and displays the LGC assumed detent and celestial body codes under flashing VERB 01 NOUN 70. These are approved or corrected as before (paragraph 7.3.2.3.5) and the astronaut repeats the procedures of auto optics positioning, marking, and celestial body definition for the second target. R51 then calls the Sighting Data Display Routine, R54 (Figure 7.3.2-11).

7.3.2.3.10 Sighting Data Display Routine.—This routine first calculates the actual angle between the two celestial bodies using the vectors obtained by the Celestial Body Definition Routine. R54 then calculates the measured angle between the two bodies using the AOT mark data and displays the difference between these two angles under flashing VERB 06 NOUN 05. R1 contains the sighting angle difference, to 0.01 deg. If the astronaut wants to try marking on a target pair again, he keys VERB 32 ENTR to recycle to R51, which requests "Please perform fine align" (paragraph 7.3.2.3.12). Any previously stored mark data will be lost.

When the astronaut is satisfied with the VERB 06 NOUN 05 sighting data, he keys PRO. R51 then calls the Gyro Torquing Routine, R55 (Figure 7.3.2-12).

7.3.2.3.11 Gyro Torquing Routine.—R55 uses the two measured LOS vectors to the celestial bodies to calculate the difference between the actual and desired stable member orientations. The routine then calculates the gyro torquing angles required to eliminate this difference and displays them under flashing VERB 06 NOUN 93. R1, R2, and R3 contain the X, Y, and Z gyro torquing angles, respectively. If the

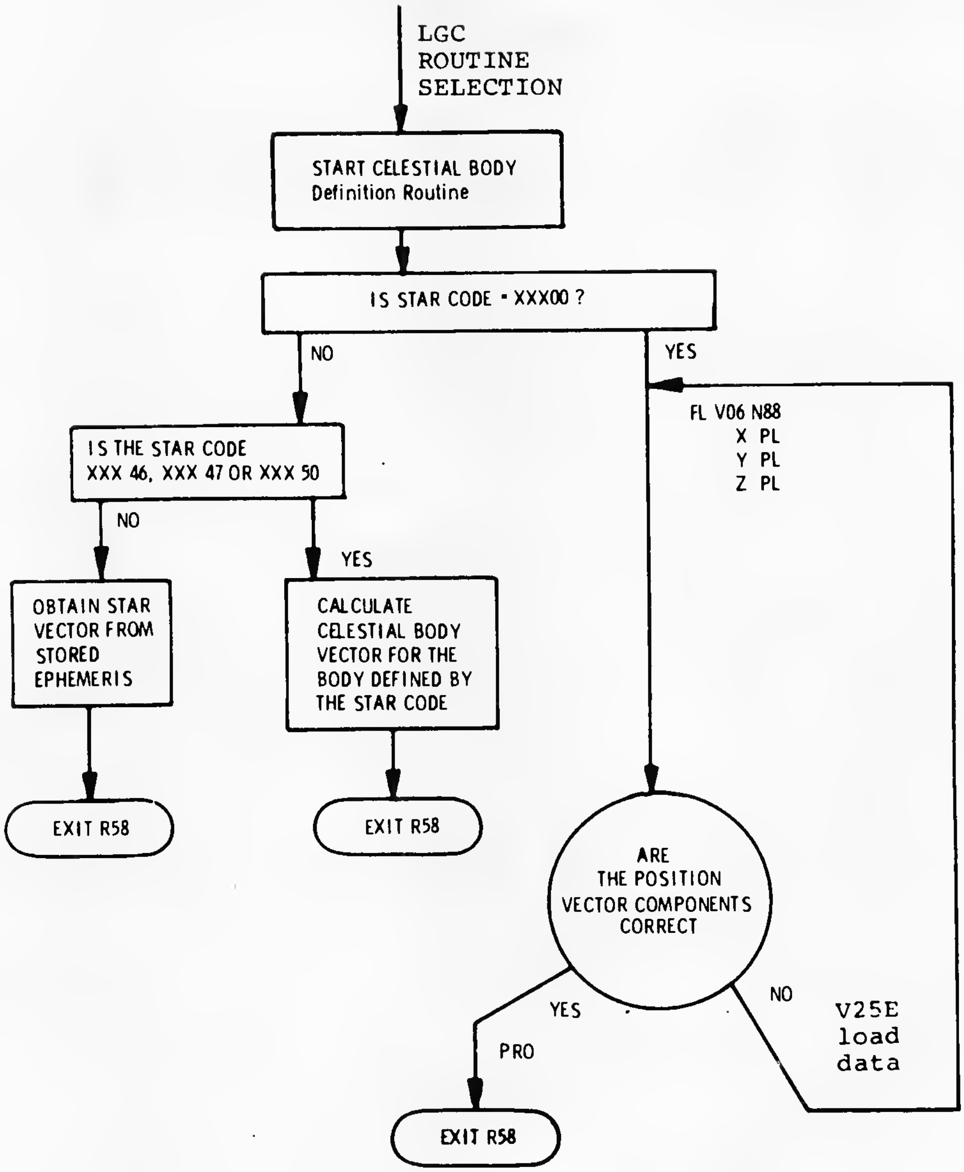


Figure 7.3.2-10. Celestial-body Definition Routine (LM R58)

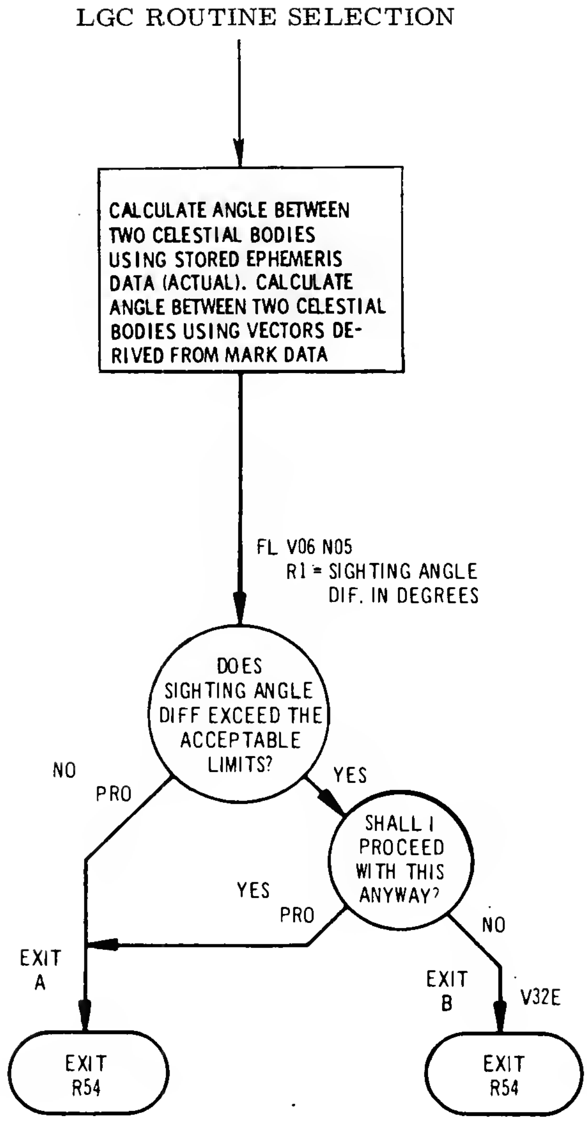


Figure 7.3.2-11. Sighting-data Display Routine (LM R54)

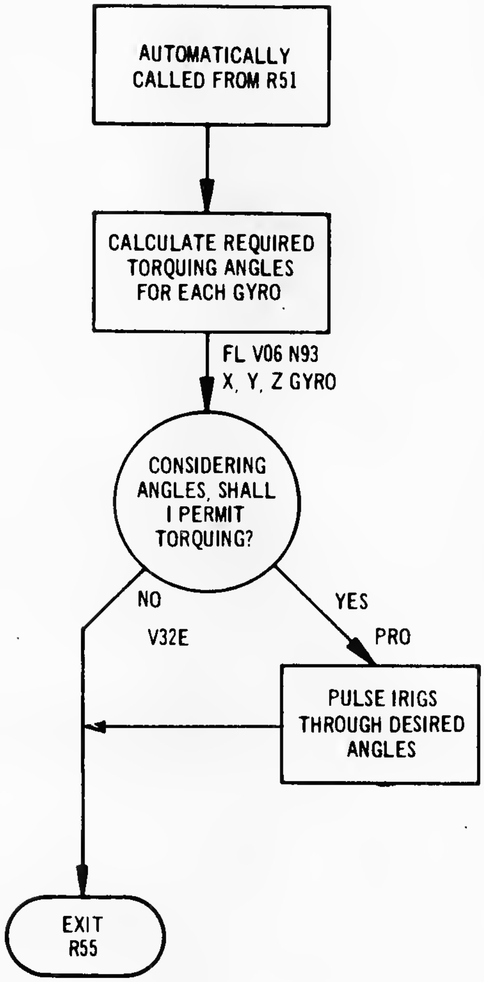


Figure 7.3.2-12. Gyro-torquing Routine (LM R55)

astronaut decides that these angles are too large or that they could cause gimbal lock, he can bypass pulse torquing by keying VERB 32 ENTR. R55 then returns control to R51 (paragraph 7.3.2.3.12). If the astronaut keys PRO on the gyro torquing angles displayed, R55 pulse-torques the stable member through the angles required to bring the stable member into precise alignment with the desired orientation (which was stored in REFSMMAT after normal or pulse-torque coarse alignment).

7.3.2.3.12 Third Star Check.—The DSKY next flashes VERB 50 NOUN 25, checklist code 00014 ("Please perform fine align"), when any of the following conditions are met:

a. Coarse align pulse torquing (paragraph 7.3.2.3.2) has been completed
b. The astronaut has terminated R54 via VERB 32 ENTR (paragraph 7.3.2.3.10)
c. The astronaut has terminated R55 via PRO or VERB 32 ENTR.

The astronaut can now key ENTR to terminate the IMU Realignment Program, or he can key PRO to recycle within R51.

If the astronaut keys PRO, he sees flashing VERB 50 NOUN 25 with checklist code 00015 ("Please perform celestial body acquisition"). The astronaut can now check the accuracy of the realignment by having the LGC select a star pair and acquire it in the AOT. He accomplishes this by following the procedures discussed in paragraph 7.3.2.3.4. P52 can be terminated after the computer performs auto optics positioning via VERB 34 ENTR, or the celestial body mark procedures can be executed to repeat the entire sequence of mark taking, LOS vector computation, and fine align pulse torquing.

7.3.2.4 Program Alarms

The alarm codes that the astronaut might encounter during LM IMU realignment are:

a. Alarm 00111 occurs if the astronaut keyed PRO when no complete pair of marks was stored in the LGC. The computer flashes VERB 54 NOUN 71, requesting marks. Key RSET and perform normal marking.
b. Alarm 00112 indicates a mark or mark reject was attempted, or if LGC received ROD input with Average-G off, while the LGC was not accepting these inputs. Control is automatically returned to the interrupted job. Key RSET and continue.

c. Alarm 00113 indicates a hardware or software failure called R57 unnecessarily. Control is automatically returned to the interrupted job. Key RSET, continue operations, and refer to backup procedures for partial computer failure.

d. Alarm 00115 indicates a mark reject was attempted with no marks to reject. Key RSET and monitor DSKY mark request.

e. Alarm 00206 indicates zeroing the ICDUs by VERB 40 NOUN 20 was attempted by the astronaut but not allowed during gimbal lock. With the IMU in coarse align mode and gimbal lock, zero CDU encoding is accomplished by first commanding coarse alignment to zero as follows: key RSET; key VERB 41 NOUN 20 ENTR and load ENTR, ENTR, ENTR; key VERB 40 NOUN 20 ENTR.

f. Alarm 00207 indicates ISS turn-on not present for 90 sec. Key RSET and reinitiate ISS turn-on sequence.

g. Alarm 00210 indicates the IMU is not on. P52 is automatically terminated. Initiate the ISS turn-on sequence and, when the NO ATT light is extinguished, execute P51 to determine the stable member orientation and REFSMMAT.

h. Alarm 00211 indicates gimbal angles are not within 2 deg of commanded position after coarse alignment. To determine size of error, key VERB 06 NOUN 20 ENTR for display of present gimbal angles and VERB 06 NOUN 22 ENTR for desired gimbal angles. Continue the alignment and record the torquing angles. Then perform the third star alignment check (paragraph 7.3.2.3.12). If performing VERB 41 NOUN 20, try again.

i. Alarm 00217 can accompany alarm 00211 and indicates a bad return from ISS mode switching. Control is returned to P52 as usual. The bad return could also be due to a power failure during coarse or fine alignment. Key RSET and perform 00211 recovery procedures.

j. Alarm 00220 indicates IMU alignment not known (REFSMMAT flag reset). Perform P51 or, if the IMU alignment is known (for example, after docked alignment), set the REFSMMAT flag. To set this flag, key VERB 25 NOUN 07 ENTR. Then key 77 ENTR, 10000 ENTR, and 1 ENTR.

k. Alarm 00404 indicates defined star not available in any detent. Specify new target or key VERB 32 ENTR to flashing VERB 01 NOUN 70.

l. Alarm 00405 indicates the computer could not find two stars in the forward AOT detent at the present LM attitude. The astronaut can maneuver the LM and key VERB 32 ENTR to have the LGC try again, or he can key PRO when he acquires a star or planet himself. When he keys PRO, the computer flashes VERB 01 NOUN 70 and displays the detent and star code assumed by the computer.

m. Alarm 31207 indicates no VAC areas are available for storing mark data. The LGC executes a software restart to the flashing VERB 01 NOUN 70 of the Auto Optics Positioning Routine, R52.

n. Alarm 31211 indicates an illegal interrupt of an extended verb in progress. The LGC executes a software restart to flashing VERB 01 NOUN 70, R52 or R59.

7.3.2.5 Program Coordination and Procedures

The following paragraphs discuss the use of P52 during a mission and miscellaneous procedures relevant to IMU realignment.

7.3.2.5.1 P52 Activities.—When the LM and CSM are docked and the LM ISS is first powered up, the LM stable member requires alignment to the landing site orientation. This can be accomplished without AOT sightings, and the CSM and LM given the same REFSMMAT, by following the procedure discussed in paragraph 7.3.2.5.3 below. P27 is used to uplink REFSMMAT to the LM after docked alignment.

After CSM/LM separation in lunar orbit, the CSM and LM stable members are each realigned to option 00003, REFSMMAT. When the LM stable member fine alignment is accomplished, the third star alignment check procedure in P52 can be used to calibrate the landing point designator (LPD) located in the LM left front window. The position of the LPD is keyed in as a COAS sighting (detent code 0 under flashing VERB 01 NOUN 70, R52). Zero deg azimuth and -40 deg elevation are keyed in when the LGC flashes VERB 06 NOUN 87. The calibration star should appear in the LPD when R60, the auto maneuver star acquisition routine, is performed.

About one and a half hours before Powered Descent Initiation (PDI), P52, option 00003, is again executed. The gyro torquing angles are used to assess the amount of drift since the previous alignment. Before lunar liftoff, the LM stable member will be realigned by P57 to the landing site orientation at liftoff. After liftoff, P52 option 00003 is executed to realign to this orientation prior to targeting for CSI (P32).

The preferred option of the LM IMU Realignment Program can be used in coordination with prethrust and thrusting programs to move the stable member into an optimum orientation for an upcoming propulsion system burn. (Refer to paragraph 7.2.2.2.1.) A typical program sequence follows:

a. The astronaut keys in one of the P30's (prethrust targeting programs, subsection 5.3). This determines the time of ignition and velocity change.

b. The astronaut keys in a thrusting program: P40, P41, or P42 (subsection 6.3). The thrusting program computes a preferred IMU orientation and vehicle attitude and sets the PREFERRED ATTITUDE-COMPUTED flag. The astronaut then sees a flashing VERB 50 NOUN 18 ("Please perform maneuver to displayed FDAI angles").

c. If the astronaut wants to realign the stable member, he does not perform the auto maneuver. Instead, he terminates thrusting program at the flashing VERB 50 NOUN 18 and keys in P52. Since the PREFERRED ATTITUDE-COMPUTED flag is set, P52 automatically chooses and displays the preferred option code (00001) for crew approval. The astronaut can then realign the stable member to this option.

d. The astronaut then returns to the beginning of the thrusting program and executes the entire program.

7.3.2.5.2 Backup-mark Procedures.—APOLLO 15 changes to alignment program coding now protect MARK X and Y interrupts in the event of ROD switch failure and allow the ROD switch to be used as a mark input during non-thrusting periods. In the event of MARK REJECT failure, rejection can always be accomplished by keying VERB 32 ENTR under the mark request display. The display then returns to VERB 01 NOUN 71. This action not only eliminates the bad mark but also all valid marks that may have accumulated for a given target. However, the astronaut does not need to reselect the alignment program.

If a ROD input fails during alignment, it will not affect MARK inputs. If the astronaut then attempts mark reject, however, he will see alarm 00113.

In the event of a failure of the X- or Y-mark inputs, the astronaut can use the lunar-surface sighting technique for a backup because X- and Y-marks can be made in either order. To select the lunar-surface technique, key VERB 32 ENTR under flashing VERB 50 NOUN 25, R1 = 00015 ("Select star acquisition mode"). Actuate the ROD switch to perform cursor and spiral marks. (This backup capability is automatically present during P57.) Actuating the ROD switch under a display other than a MARK request verb will cause alarm 00112 if Average-g (powered flight) is not active.

7.3.2.5.3 Miscellaneous Procedures.—The docked alignment procedure is discussed here:

a. The CSM IMU is aligned to the landing site orientation and the LM crew notes the docking ring angle during inter-vehicle transfer.

b. CSM attitude is held at minimum deadband and the LM stable member is coarse aligned (VERB 41 NOUN 20) to angles in degrees as follows:
outer gimbal angle (LM) = 300 + docking ring number
-outer gimbal angle (CSM);
inner gimbal angle (LM) = inner gimbal angle (CSM) + 180;
middle gimbal angle (LM) = -middle gimbal angle (CSM).

c. LM CDUs are zeroed (VERB 40 NOUN 20), and CSM attitude hold can now be terminated. Hold terminated.

d. The REFSMMAT flag is set as follows: VERB 25 NOUN 07 ENTR; 77 ENTR; 10000 ENTR; 1 ENTR. Bit 13 is confirmed to be set if VERB 01 NOUN 01 ENTR 77 ENTR produces 1, 3, 5, or 7 in the first digit of R1.

e. The DRIFT (gyro compensation available) flag is now set as follows: VERB 37 ENTR 51 ENTR; PRO; VERB 37 ENTR 00 ENTR.

f. The CM and LM pilots both key VERB 06 NOUN 20 and on the LM pilot's "Mark," they key ENTR to display the present gimbal angles.

g. The gimbal angles and time are voiced to the ground where the torquing angles are calculated for fine alignment. The desired torquing angles are then voiced to the LM.

h. The LM crew should verify that the minimum impulse mode has been commanded and then key VERB 42 ENTR.

i. When the LGC flashes VERB 21 NOUN 93, the gyro torquing angles are loaded. NOUN 20 can be used to monitor the current gimbal angles. Alignment is complete.

While the spacecraft are docked before PDI, an IMU drift check is performed. The ground notes any changes in the difference between the CSM and LM gimbal angles. If any gyro drift exceeds 1.5 deg per hour, either the CSM or LM IMU has failed.* Since the CSM IMU has been powered up since launch, with several realignment and drift checks, it is more probable that the LM IMU has failed if the change in the difference between the LM and CSM gimbal angles becomes too large.

*Refer to paragraph 7.2.2.5 for a discussion of the gyro drift measurement equations.

If the AGS has a good alignment, it can be used to rapidly realign the LM IMU by the following procedure:

a. Maneuver the LM to (0,0,0) on the AGS FDAI ball.
b. Key VERB 41 NOUN 20 ENTR, ENTR, ENTR, ENTR. This coarse aligns the IMU to (0,0,0) gimbal angles.
c. Key VERB 40 NOUN 20, verify that the FDAI is at (0,0,0), and key ENTR. This zeros the ICDUs and recovers stable member inertial reference capability.
d. After 15 sec, key VERB 37 ENTR 51 ENTR and PRO on the first display. This sets the DRIFT flag. Then key VERB 37 ENTR 00 ENTR.
e. To set the REFSMMAT flag, key VERB 25 NOUN 07 ENTR, 77 ENTR, 10000 ENTR, 1 ENTR.
f. If the LGC has auto optics positioning capability, perform P52, REFSMMAT option.

7.3.2.6 Extended Verbs

The extended verbs discussed below are not executed during P52. They do, however, allow the crew to control the normal and gyro torque repositioning of the stable member. Table 7.3.2-II lists the extended verbs' DSKY activity.

The Coarse Align ISS extended verb, VERB 41 NOUN 20, is used to coarse-align the gimbal angles to values specified by the astronaut (Figure 7.3.2-13). This verb is used to align the gimbals to zero (or any other value) when in coarse align mode with a gimbal lock. The astronaut keys VERB 41 NOUN 20 ENTR, loads the angles, and the computer commands the coarse align ISS mode to reposition the stable member. The specified gimbal angles can be displayed by keying VERB 16 NOUN 22 ENTR; the current gimbal angles can be monitored by keying VERB 16 NOUN 20 ENTR. The NO ATT light remains illuminated after VERB 41 NOUN 20 is completed. This extended verb should never be used during a process that requires the stable member to be at a known inertial orientation, because inertial reference is not maintained during coarse alignment.

The Fine Align extended verb, VERB 42 (Figure 7.3.2-14) is used to pulse torque the stable member and to switch the ISS from the coarse align to the fine align mode. The operator, after keying VERB 42 ENTR, observes flashing VERB 21 NOUN 93 and loads the gyro torquing angles. In flight, all torquing angles must be less than 100 deg and must be chosen to keep the middle gimbal angle less than 70 deg (gimbal lock imminent). Note that the coarse and fine align extended verbs

provide neither a means of determining the stable member's inertial orientation nor a means of alignment to one of P52's alignment options.

The IMU CDU-Zero extended verb (VERB 40 NOUN 20) is used to switch the ISS from coarse align to fine align mode and to synchronize the ISS CDU counters and the CDU counters in the LGC (Figure 7.3.2-15). This verb cannot be entered when the ISS is in the coarse align mode with a gimbal lock. If a gimbal lock has occurred, VERB 41 NOUN 20 must precede VERB 40 NOUN 20. When VERB 40 NOUN 20 is executed, the NO ATT light will be turned off by the LGC.

TABLE 7.3.2-II

EXTENDED VERBS ASSOCIATED WITH LM IMU REALIGNMENT

VERB	Identification	Purpose	Remarks
V41 N20	Coarse align ISS extended verb	Coarse align stable member to gimbal angles specified by astronaut	Astronaut keys in V41 N20 ENTR to initiate coarse alignment. LGC then flashes V21 N22 requesting astronaut to load gimbal angles desired. Astronaut loads outer, inner, and middle gimbal angles in DSKY registers R1, R2, and R3, respectively. LGC then displays V41 while stable member is reoriented. The NO ATT light remains illuminated during coarse alignment and after the coarse align ISS extended verb has terminated.
V42	Fine align ISS extended verb	Pulse torque stable member through angles indicated by astronaut	Astronaut keys in V42 ENTR. LGC then flashes V21 N93 requesting astronaut to load delta gyro angles. Astronaut then loads outer, inner, and middle gimbal delta gyro angles into registers R1, R2, and R3, respectively. LGC then displays V42 while pulse torquing is in progress, and the NO ATT light is extinguished.
V40 N20	IMU CDU Zero extended verb	Recover ISS inertial reference capability and synchronize ISS CDU counters and LGC CDU counters	Astronaut keys V40 N20 ENTR. LGC then extinguishes NO ATT light, sets ICDU zero discrete, clears and zeroes LGC ICDU counters. It then enables DAP AUTO and HOLD modes.

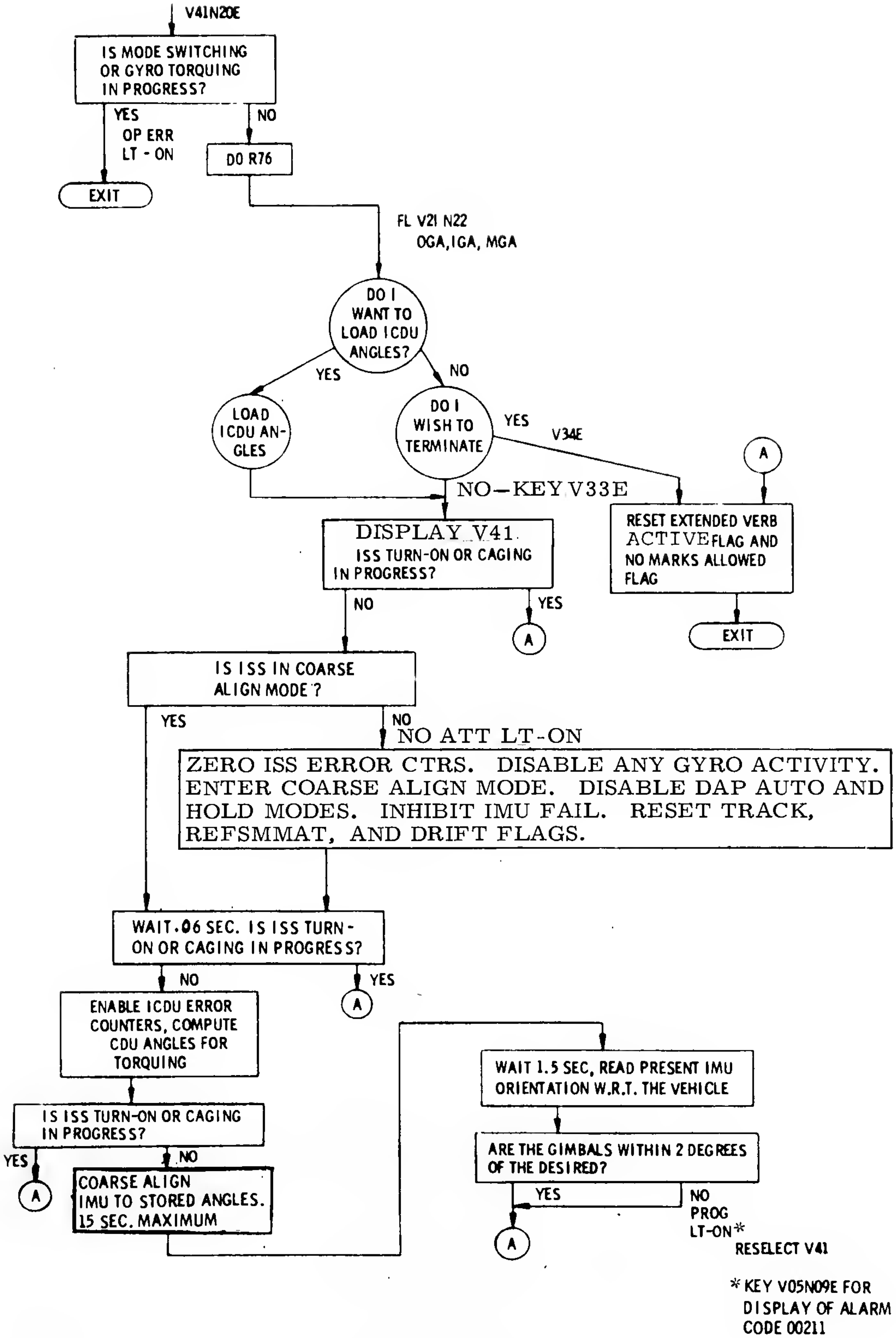


Figure 7.3.2-13. Coarse-align ISS (Extended Verb V41 N20)

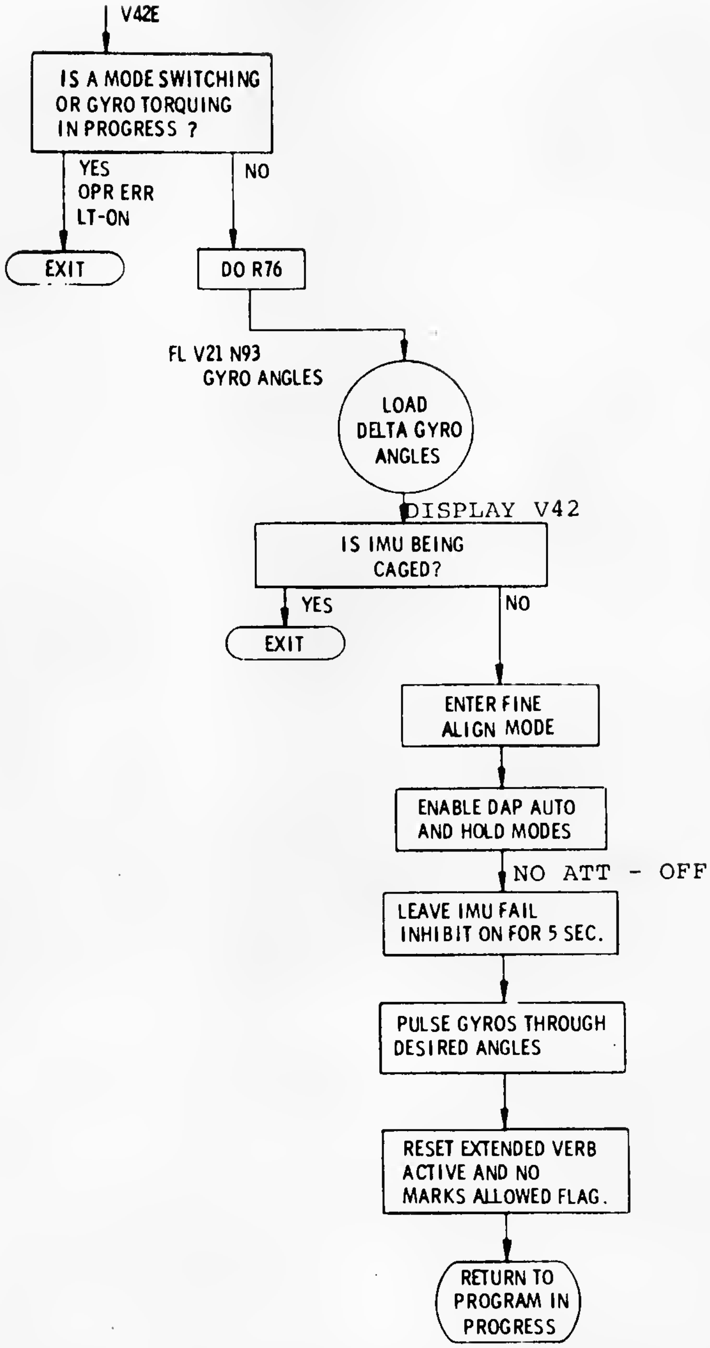


Figure 7.3.2-14. Fine-align IMU (Extended Verb V42)

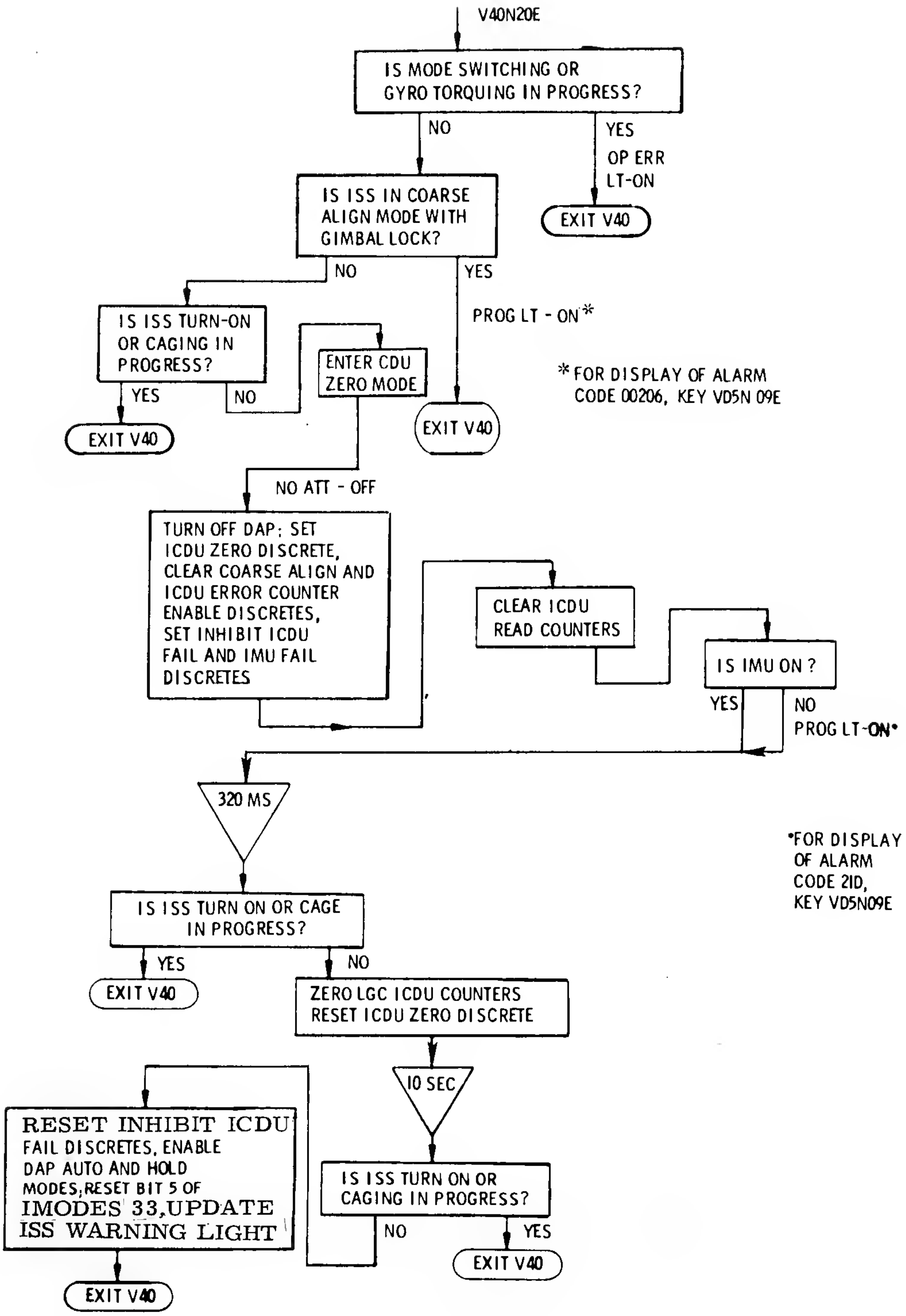


Figure 7.3.2-15. IMU-ICDU Zero (Extended Verb V40 N20)

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7.3.3 P57, Lunar Surface Align—LGC

The LM crew uses the Lunar Surface Alignment Program (P57) to perform the following PGNCS functions during the lunar-surface phase of the LM mission:

a. IMU alignment to a desired inertial orientation
b. calculation of the lunar landing-site radius vector ($\underline{R}_{LS}$)
c. calculation of the LM attitude on the lunar surface.

P57 performs these tasks by not only measuring AOT lines-of-sight to celestial bodies, but also by measuring the direction of the local-gravity vector with respect to the LM navigation base. In performing a P57 alignment, the astronaut must select the kind of measurement (celestial-body line-of-sight or gravity) required for the situation.

Paragraph 7.3.3 is organized as follows: paragraph 7.3.3.1 describes the options and measurement techniques available in P57; paragraph 7.3.3.2 gives a general outline of P57; and paragraph 7.3.3.4 describes P57's logic flow in detail. Paragraph 7.3.3.5 covers the program alarms, and paragraph 7.3.3.6 describes miscellaneous procedures associated with P57.

7.3.3.1 Lunar Surface Alignment Options

To realign the stable member with P57, the astronaut must first select a desired stable-member inertial orientation from among the following options: (a) Preferred; (b) REFSMMAT; (c) Landing Site. The Nominal orientation option is not used with P57.

After selecting a stable-member orientation, the astronaut must decide which kind of measurement P57 will use in calculating the IMU gimbal-angle changes required to perform the alignment. As discussed in subsection 7.1, the inflight alignment programs measure celestial-body line-of-sight (LOS) vectors to calculate the difference between the present and desired stable-member inertial orientations. In P57, however, the astronaut must select one of the following options for LGC-measured vectors:

a. LM Y- and Z-body axes
b. local-gravity vector and LM Z-axis
c. lines-of-sight to two celestial bodies (same as P52)
d. local-gravity vector and line-of-sight to one celestial body.

The four alignment techniques available in P57 are discussed in detail here.

7.3.3.1.1 <u>Alignment Technique 0 (AT-0): Two LM Body Axes.</u>—AT-0 is used if an emergency liftoff is required with no time available to perform celestial-body sightings or gravity measurements. P57 can align the stable member to a liftoff orientation by using only the LM attitude vectors that were computed and stored by P68 or by a previous P57. The main sources of error in this fast alignment are the LM settling since the previous alignment, and the error, if any, in the REFSMMAT used to determine the LM attitude. The IMU drift rate (0.015 degree per hour in APOLLO 12) is small enough to ensure a sufficiently adequate attitude determination shortly after touchdown as the basis for an AT-0 fast alignment for liftoff.

The information processing for AT-0 alignments follows the scheme outlined here:

a. The LGC obtains the LM Y- and Z-axes from storage in moon-fixed coordinates and transforms them to basic-reference coordinates. (If REFSMMAT is valid, it is used by P57 to compute the LM attitude.) The axes are then transformed from basic-reference to desired stable-member coordinates.
b. The LM Y- and Z-axes in present stable-member coordinates are computed from the current IMU gimbal angles.
c. The Y- and Z-axes, in present and desired stable-member coordinates, are used as AXISGEN inputs to compute the desired stable-member axes with respect to the present Stable Member Coordinate System.
d. The relationship between the present and desired axes is used to calculate the IMU gimbal-angle changes needed to achieve the desired stable-member inertial orientation.

7.3.3.1.2 <u>Alignment Technique 1 (AT-1): Gravity and One LM Axis.</u>—If poor lighting conditions or an unfavorable LM attitude prevent the astronaut from taking celestial-body sightings, an acceptable liftoff alignment can be obtained by using the gravity vector to determine pitch orientation and the stored LM Z-axis to determine azimuth orientation. P57 automatically obtains an accurate pitch alignment; an error, however, in the stored LM attitude could affect the azimuth component of the alignment. Azimuth errors do not affect the insertion-orbit flightpath angle.

Vectors measured by AT-1 are processed as follows:

a. The measured gravity vector is stored in navigation-base coordinates and transformed to present stable-member coordinates. [P57 assumes

that the gravity vector and the true landing-site radius vector, ($\underline{R}_{LS}$) represent the same direction in inertial space.] The LM Z-axis is calculated, in present stable-member coordinates, from the current gimbal angles.

b. The LM Z-axis and $\underline{R}_{LS}$ are obtained from storage and transformed from moon-fixed to basic-reference coordinates, then to desired stable-member coordinates.

c. The following vectors are used as AXISGEN inputs to determine the relationship between present and desired stable-member orientations: LM Z-axis and $\underline{R}_{LS}$, in desired stable-member coordinates; and the LM Z-axis and the gravity vector, in present stable-member coordinates.

d. The LGC calculates the gimbal-angle changes required for the desired stable-member orientation.

7.3.3.1.3 Alignment Technique 2 (AT-2): Two Celestial Bodies.—AT-2 uses AOT-measured lines-of-sight to two celestial bodies to calculate the difference between the present and desired stable-member orientations. An AT-2 alignment can be accomplished without both a previously stored LM attitude and a present REFSMMAT, and provides accurate pitch and azimuth information.

During AT-2, as in P52, the astronaut measures an LOS to two celestial bodies in present stable-member coordinates. The program then calculates the LOS for the same two targets in desired stable-member coordinates, using the celestial bodies' stored basic-reference coordinates. AXISGEN then calculates the relationship between present and desired IMU orientations. After the stable member is aligned to the desired orientation, the astronaut can choose to have AT-2 calculate the landing-site vector based on the celestial-body sightings. The program also updates the stored LM attitude by using the AT-2 sighting information.

7.3.3.1.4 Alignment Technique 3 (AT-3): Gravity and One Celestial Body.—Two AT-3 alignments are performed before liftoff to align the stable member to the desired orientation. AT-3 measures the gravity vector and the LOS to one celestial body. An AT-3 alignment can be performed in the absence of both stored LM attitude data and a valid REFSMMAT, and can replace AT-2 if only one celestial body is available for sightings.

Alignment information processing during AT-3 is outlined here:

a. The measured gravity vector is stored in navigation-base coordinates and transformed to present stable-member coordinates. The LOS to a celestial body is also measured in present stable-member coordinates.

b. P57 obtains $\underline{R}_{LS}$ from storage in moon-fixed coordinates and transforms it to basic-reference coordinates, then to desired stable-member coordinates. The stored celestial body LOS is obtained in basic-reference coordinates and transformed to desired stable-member coordinates.

c. The measured vectors, in present stable-member coordinates, and the stored vectors, in desired stable-member coordinates, are used by AXISGEN to calculate the difference between the present and desired IMU orientation.

d. The LGC calculates the gimbal-angle changes required for the desired stable-member orientation. AT-3 also computes and stores the LM attitude in moon-fixed coordinates.

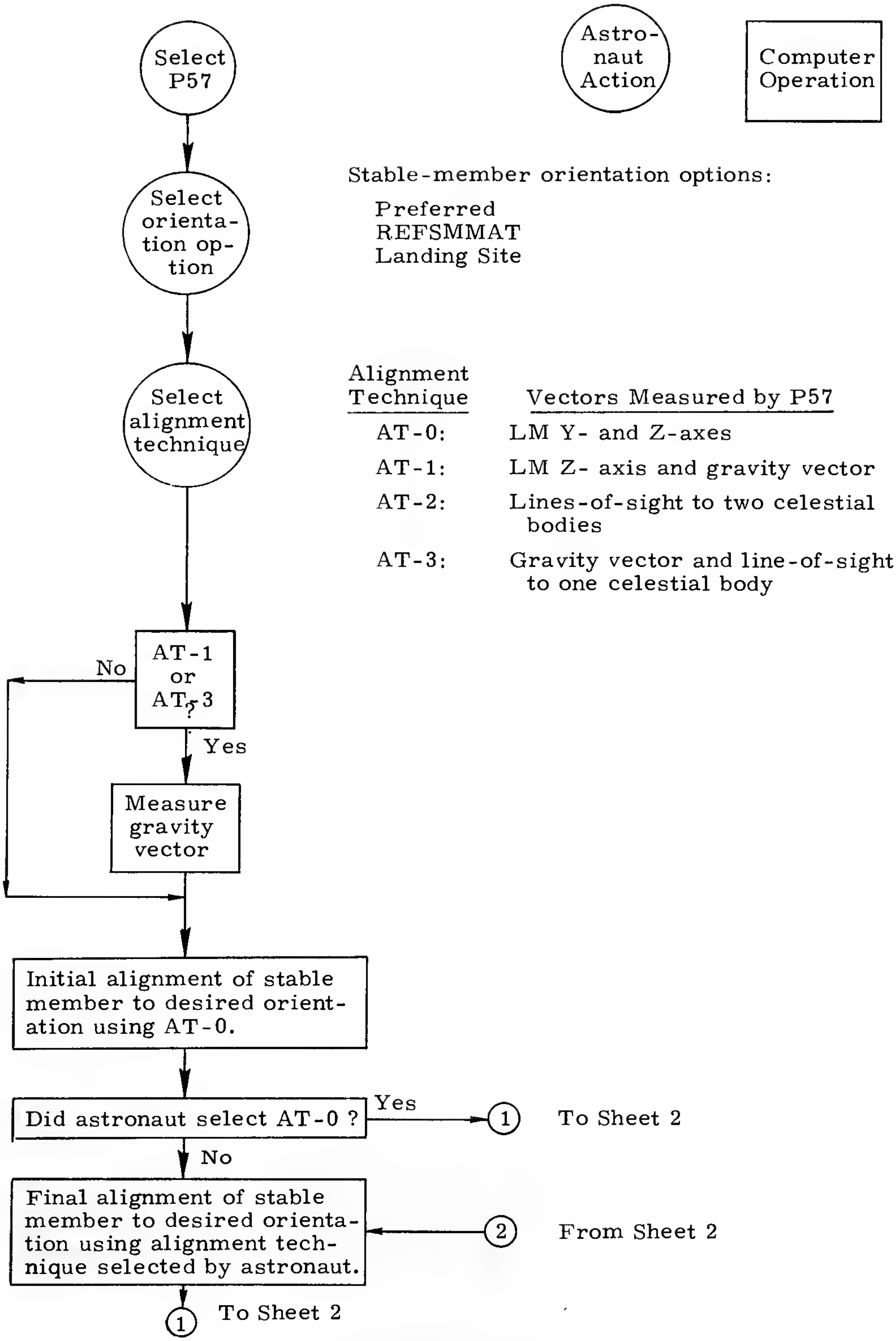
After the celestial-body sighting has been taken, AT-3 calculates the angle, in desired stable-member coordinates, between $\underline{R}_{LS}$ and the stored celestial body LOS vector. The program also calculates the angle between the gravity vector and measured celestial-body LOS vector, in present stable-member coordinates. The difference between these angles (measured minus stored value) is displayed to the astronaut, and enables the MSFN to calculate the angle between the LGC-stored $\underline{R}_{LS}$ and the gravity vector. Neglecting gravitational anomalies, the gravity vector represents the orientation of the true landing site. Two or more AT-3 sightings on different celestial bodies then enable the ground to estimate the latitude and longitude of the gravity vector.

7.3.3.2 P57 General Outline

After starting P57, the astronaut first selects the desired stable-member orientation and the alignment technique used to achieve this orientation. (Refer to Figure 7.3.3-1.) If there is a valid REFSMMAT in storage, the LGC computes and stores the LM attitude on the lunar surface. If a gravity measurement is required (AT-1 or -3), the computer measures the local-gravity vector and stores it in navigation-base coordinates.

P57 next performs an initial alignment of the stable member to the desired orientation, using the stored LM attitude information (AT-0). If the stored LM attitude is accurate, the initial alignment brings the stable member very close to the desired orientation. If the astronaut chose AT-0, he can now either repeat the initial alignment or exit P57.

For alignment techniques AT-1, -2, and -3, the initial stable-member alignment is followed by a final alignment to the desired orientation using the technique specified



Stable-member orientation options:

Preferred
REFSMMAT
Landing Site

Alignment Technique	Vectors Measured by P57
AT-0:	LM Y- and Z-axes
AT-1:	LM Z- axis and gravity vector
AT-2:	Lines-of-sight to two celestial bodies
AT-3:	Gravity vector and line-of-sight to one celestial body

Figure 7.3.3-1. P57 General Outline (Sheet 1 of 2)

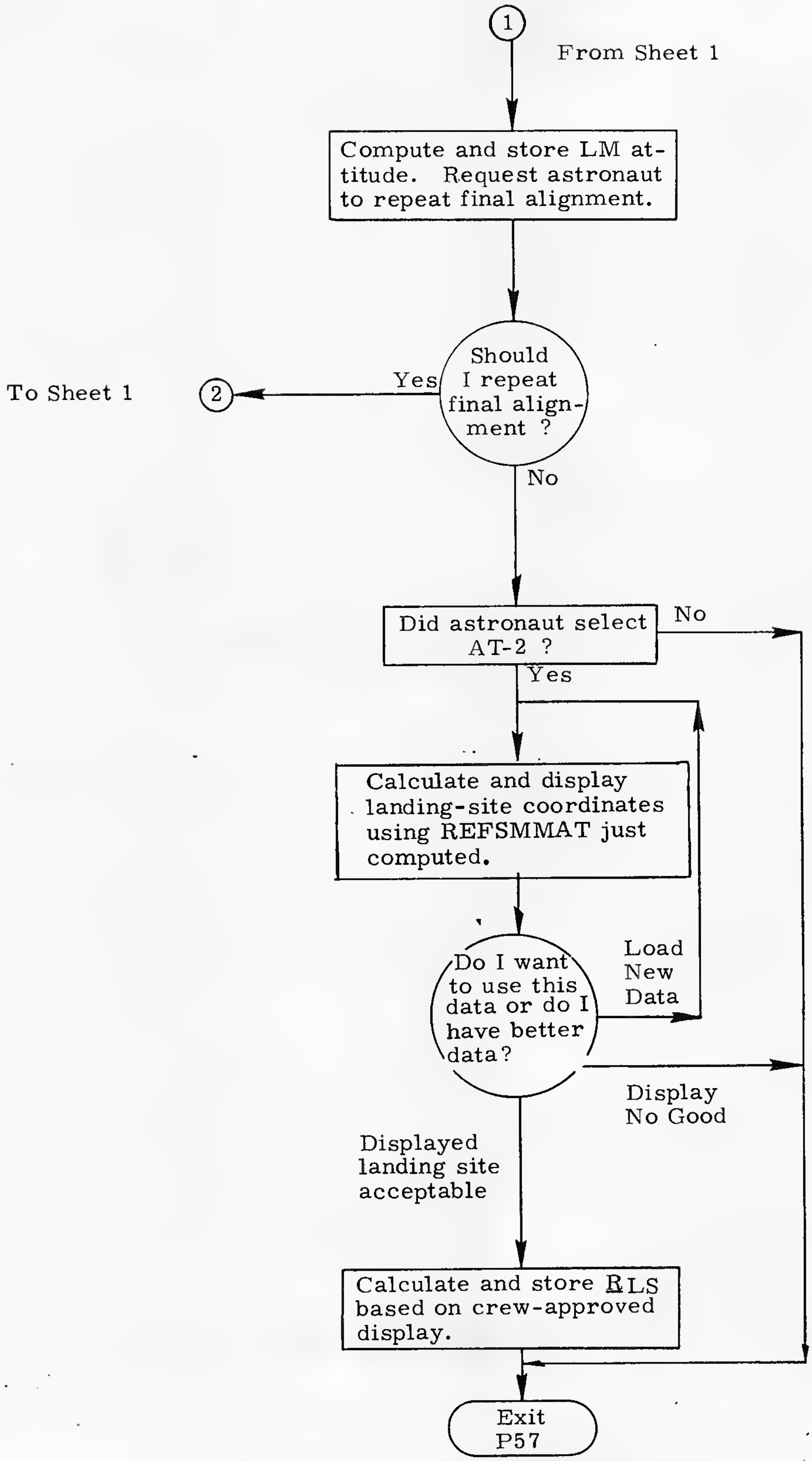


Figure 7.3.3-1. P57 General Outline (Sheet 2 of 2)

by the astronaut. For AT-2 and -3, the final alignment includes celestial-body AOT sightings. After the final alignment, the LGC again computes and stores the LM attitude. The final alignment can be repeated by the astronaut at his discretion. If the astronaut chose AT-2, he can request the LGC to use the AOT sighting information and the last determination of a gravity vector to compute and display the coordinates of the actual landing site.

7.3.3.3 Related Routines

P57 uses five related routines. All but one of them are associated only with celestial-body sightings (AT-2 or -3). The routines are listed below:

a. AOT Mark Routine (R53)
b. Sighting Data Display Routine (R54)
c. MARKRUPT Routine (R57)
d. Celestial Body Definition Routine (R58)
e. Lunar Surface Sighting Mark Routine (R59)

The Lunar Surface Sighting Mark Routine (R59) is called by P57 when celestial-body sightings are required. R59 obtains estimates of the cursor and spiral angles for the intended celestial body and calls the AOT Mark Routine (R53). R53 requests the astronaut to mark on the target. The astronaut calls the MARKRUPT Routine (R57) by depressing a MARK pushbutton. R57 stores mark inputs associated with the celestial body sighting. R53 then calculates the measured value of the celestial-body LOS vector. The Celestial Body Definition Routine (R58) obtains the stored LOS vector for the target used by the astronaut. P57 then transforms the stored lines-of-sight from basic-reference to desired stable-member coordinates and calls the Sighting Data Display Routine (R54) to calculate the difference between the measured and stored lines-of-sight. The crew decides whether to reorient the stable member by using the sighting information or to take new sightings and perform the final alignment again. R54 is also called during AT-1 and -3 to display the difference between the measured and stored values of the angle between the vectors used in the alignment.

7.3.3.4 P57 Computational Sequence

The following paragraphs discuss the calculations and crew procedures that take place during P57. Table 7.3.3-I lists P57's displays.

TABLE 7.3.3-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM LUNAR SURFACE ALIGNMENT (LM P57) (SHEET 1 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
1	V37 ENTR 57 ENTR	Astronaut	Initiate P57	---	---	---
2	FL V04 N06	P57	Request response to display of orientation option code.	IMU operating R1--please specify IMU orientation option R2--option assumed by LGC 00001 = Preferred 00003 = REFSMMAT 00004 = Landing site	R1 00001 check list R2 0000x R3 Blank	Load desired option. Preferred-PRO to 4. REFSMMAT-PRO to 4. Landing site-PRO to 3.
3	FL V06 N34	P57	Request response to display of time of alignment.	Landing site option. R1, R2, R3--time of alignment (GET) at which LM position vector is defined for a landing site orientation; all zeroes indicates present time.	R1 00xxx hr R2 000xx min R3 0xx.xx sec	Load desired time. PRO to 4.
4	FL V05 N06	P57	Request response to display of LGC assumed alignment technique (AT).	R1--please specify alignment technique R2--LGC assumed alignment technique 00000 = alignment using stored LM attitude or REFSMMAT. (cont.)	R1 00010 R2 oooox R3 00CD0	Select desired AT. Then: AT-0 or 2 with no valid REFSMMAT-PRO to 16. (cont.)

TABLE 7.3.3-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM LUNAR SURFACE ALIGNMENT (LM P57) (SHEET 2 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
4 cont.				00001 = alignment using LM attitude and local gravity vector. 00002 = alignment using AOT sightings to two celestial bodies. 00003 = alignment using local gravity vector and one celestial body sighting. R3--C = 1: REFSMMAT is defined; C = 0: REFSMMAT is not defined. D = 1: LM attitude available from storage. D = 0: LM attitude not available from storage.		AT-0 with valid REFSMMAT-PRO to 16. AT-1 or 3-set ATTITUDE MON to PGNCS, PRO to 5. AT-2 with valid REFSMMAT-PRO to 7. Alarm 00701 indicates REFSMMAT or attitude not available.
5	V16 N20 ENTR	Astronaut	Monitor lunar gravity measurement.	AT-1 or AT-3. Monitor present ICDU angles. R1--outer gimbal R2--inner gimbal R3--middle gimbal	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg	No ATT and NO DAP lights go on, then off (twice). Hit KEY REL. Go to 6.
6	FL V06 N04	P57	Request response to display of gravity error angle.	R1--angular difference between present and previous gravity vector.	R1 xxx.xx deg R2 Blank R3 Blank	Note gravity error angle. To recycle, V32 (cont.)

TABLE 7.3.3-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM LUNAR SURFACE ALIGNMENT (LM P57) (SHEET 3 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
6 cont.						ENTR to 5. To terminate, V34 ENTR. To continue, PRO to 16.
7	FL V01 N70	R59	Request response to display of AOT detent celestial body codes.	R1--AOT detent and star codes Detente Code C (not required) = 1-front left detent = 2-front center detent = 3-front right detent = 4-rear right detent = 5-rear center detent = 6-rear left detent = 7-backup optics Celestial body code DE = 00-planet = 01/45–star = 46, 47, 50–sun, earth, moon	R1 00CDE R2 Blank R3 Blank	Load desired code. PRO to 8 (to 7a if DE = 00). Alarm 00404 indicates star not available in any detent. PRO to 9 or V32 ENTR to 7.
7a	FL V06 N88	R58	Request response to display of celestial body vector.	R1--Xpl R2--Ypl R3--Zpl Target Code = 00 Xpl-the X-component of the LGC-assumed celestial body vector in reference coordinates at GET. (cont.)	R1 .xxxxx R2 .xxxxx R3 .xxxxx	Load vector. PRO to 8.

TABLE 7.3.3-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM LUNAR SURFACE ALIGNMENT (LM P57) (SHEET 4 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
7a cont.				Ypl-same as Xpl for Y-component Zpl-same as Xpl for Z-component		
8	FL V06 N79	R59	Request response to display of required cursor and spiral angles and position code.	R1--cursor angle; the angle displayed on AOT readout counter when target is bracketed by cursor. R2--spiral angle; angle when target bracketed by spiral. R3--code for required AOT detent	R1 xxx.xx deg R2 xxx.xx deg R3 xxxxx	To redefine star, V32 ENTR to 7. PRO to 9.
9	FL V01 N71	R53	Request response to display of detent and star codes.	R1--C-detent, DE-celestial body codes.	R1 00CDE R2 Blank R3 Blank	Load desired code. PRO to 10 (to 9a if C = 7).
9a	FL V06 N87	R53	Request response to display of backup optics LOS.	R1--Backup optics azimuth. R2--Backup optics elevation.	R1 xxx.xx deg R2 xxx.xx deg R3 Blank	PRO to 10.

TABLE 7.3.3-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM LUNAR SURFACE ALIGNMENT (LM P57) (SHEET 5 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
10	FL V52/ 53 N71	R53	Request mark on body with cursor (V52) or spiral (V53).	C = detent; DE = star code S = mark reject pointer M = cursor mark counter N = spiral mark counter	R1 00CDE R2 S000M R3 S000N	To redefine star, V32 ENTR to 9. To mark cursor, key ENTR if V53 is flashing, mark with X or Y button or ROD switch. To mark spiral, key ENTR if V52 is flashing, mark with X or Y button or ROD switch. Key ENTR to reverse mark verb and mark reject pointer. To terminate marks, key PRO. If LGC rejects mark data, go to 13. If planet code used go to 13a. Otherwise go to 7 after first star (to 14 if option 00003); to 14 after second star.
11	V21/22 N79	R57	Request key in of cursor angle V21 or spiral angle V22.	Load request appears when either mark button or ROD is depressed in step 10.	R1 xxx.xx deg R2 xxx.xx deg R3 Blank	Load cursor or spiral angle. If cursor/spiral angle not changed from previous load Key VERB PRO.
12	FL V06 N79	R57	Display and request response to cursor or spiral angle data entry.	Display appears when cursor or spiral angle is loaded in step 11.	For cursor data; R1 xxx.xx deg R2 Blank R3 Blank For spiral data; R1 Blank R2 xxx.xx deg R3 Blank	Verify cursor or spiral angle. PRO to 10 Load new angle--V21 or V22 ENTR xxx.xx ENTR Mark counter increments by 1.

TABLE 7.3.3-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM LUNAR SURFACE ALIGNMENT (LM P57) (SHEET 6 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
13	FL V50 N25	R53	Possible display to request response if mark data rejected.	Display appears only if the LGC star vector computation rejects mark data. R = number of mark data sets rejected.	R1 00016 R2 0000R R3 Blank	To continue alignment with average star vector computed from non-rejected mark data, key PRO. If planet code used, go to 13a. ENTR to 9 to redo marking. VERB 34 ENTR to terminate.
13a	FL V06 N88	R58	Request response to display of celestial body vector.	DE = 00 in step 10. R1 --X planet unit R2 --Y vector R3 --Z components	R1 .xxxxx Xpl R2 .xxxxx Ypl R3 .xxxxx Zpl	Load desired components. Key PRO.
14	FL V06 N05	R54	Request response to display of sighting angle difference.	R1--sighting angle difference defined as follows: AT-0— angle between LM Y-and Z-axis in present stable member coordinates minus same angle in desired stable member coordinates; AT-1— angle between gravity vector and present LM Z-axis minus angle between $\underline{R}_{LS}$ and desired LM Z-axis; AT-2— measured minus actual value of angle between targets; (cont.)	R1 xxx.xx deg R2 Blank R3 Blank	If angle is unsatisfactory, V32 ENTR to 17. To accept, PRO to 15. To exit P57, V34 ENTR.

TABLE 7.3.3-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM LUNAR SURFACE ALIGNMENT (LM P57) (SHEET 7 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
14 cont.				AT-3—angle between gravity vector and measured target minus angle between $\underline{R}_{LS}$ and stored target.		
15	FL V06 N93	P57	Request response to display of gyro torquing angles.	R1--X gyro torquing angle R2--Y gyro R3--Z gyro	R1 xx.xxx deg R2 xx.xxx deg R3 xx.xxx deg	Reject–V32 ENTR to 17. Accept and torque gyros–PRO to 17. V34ENTR to exit.
16	FL V06 N22	P57	Request response to display of gimbal angles after proposed realignment.	Display occurs on first pass of P57 if any torquing angle is greater than five degrees. R1--outer gimbal R2--inner gimbal R3--middle gimbal	R1 xxx.xx deg R2 xxx.xx deg R3 xxx.xx deg	AT-1: PRO to 14. AT-2 or AT-3: PRO to 7. Observe NO ATT light on, then off.
17	FL V50 N25	P57	Request repeat fine alignment.	R1--please recheck or exit fine align.	R1 00014 checklist R2 Blank R3 Blank	If in AT-2 or AT-3 and wish to recheck alignment, PRO to 7. To terminate, V34 ENTR. If in AT-2 and have previously completed AT-1 or AT-3 and want present LM lunar position, key ENTR to 18.

TABLE 7.3.3-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM LUNAR SURFACE ALIGNMENT (LM P57) (SHEET 8 OF 9)

No.	DSKY	Initiated By	Purpose	Condition	Register	Crew Action
18	FL V06 N89	P57	Request response to display of landing site coordinates.	R1--LM lunar surface latitude (+ North) R2--LM longitude/2 (+ East) R3--LM altitude above lunar radius at most recently defined landing site.	R1 xx.xxx deg R2 xx.xxx deg R3 xxx.xx n.mi.	If display acceptable PRO to exit P57. If display not acceptable and have no better data, key V34 ENTR to exit. If astronaut has better data, load it via V25 ENTR to 18.
	V05 N09 ENTR	Astronaut	Display alarm codes stored by LGC.	Alarm codes displayed as follows: 00111--not enough marks to compute target vector 00112--mark or mark reject made but not needed 00113--R57 was called unnecessarily by hardware or software failure 00115--mark reject attempted with no marks to reject 00207--ISS turn-on request not present for 90 sec 00210--IMU not on	R1 xxxxx R2 xxxxx R3 xxxxx	

TABLE 7.3.3-I

REGULAR VERBS AND DSKY DISPLAYS ASSOCIATED WITH LM LUNAR SURFACE ALIGNMENT (LM P57) (SHEET 9 OF 9)

DSKY	Initiated By	Purpose	Condition	Register
V05 N09 ENTR	Astronaut	Display alarm code stored by LGC	00211--coarse align error 00217--bad return from ISS mode switch	R1--xxxxx R2--xxxxx R3--xxxxx
FL V05 N09	R59	Display alarm code	00404--desired celestial body cannot be acquired in AOT	
FL V05 N09	P57	Display alarm code	00701--illegal alignment technique code selected	
V05 N09 ENTR	Astronaut	Display alarm codes stored by LGC	31207--no VAC available 31211--illegal interrupt of extended verb	

7.3.3.4.1 Program Initiation.—The astronaut starts P57 (Figure 7.3.3-2) by keying VERB 37 ENTR 57 ENTR on the DSKY. P57 checks whether or not the IMU is on; if the IMU is off, the program illuminates the PROG alarm light, stores alarm code 00210, and terminates. If the IMU is on, the program sets the stable-member orientation option code equal to 00003 (REFSMMAT). The first display the crew sees in P57 is flashing VERB 04 NOUN 06. DSKY register R1 contains option code 00001 ("Please specify desired IMU orientation"), and R2 contains the orientation option code assumed by the LGC. These codes are as follows:

00001—Preferred Orientation
00003—REFSMMAT Orientation
00004—Landing Site Orientation

The astronaut approves the display be keying PRO or reloads the option code via VERB 22 ENTR.

If the astronaut selected the landing-site orientation, he next sees flashing VERB 06 NOUN 34, displaying the time of alignment (T_{align}) that defines the landing-site inertial orientation. P57 sets T_{align} equal to the stored time of ascent stage ignition (t_{IG}). The astronaut can reload this value via VERB 25 ENTR. If T_{align} is zero, P57 defines the time of alignment to be the present time. If T_{align} is greater than the present time, P57 replaces the stored value of t_{IG} with the value of T_{align}. If T_{align} is less than the present time, P57 does not change the value of t_{IG}. After the astronaut keys PRO to approve the displayed T_{align}, the program calculates the landing-site inertial orientation defined by T_{align}.

The LGC next flashes VERB 05 NOUN 06. R1 contains option code 00010 ("Please specify alignment technique"), and R2 contains the option code for the LGC-assumed alignment technique. The alignment technique option codes are defined as follows:

00000—LM attitude (AT-0)
00001—LM attitude and gravity (AT-1)
00002—Two celestial bodies (AT-2)
00003—Gravity and one celestial body (AT-3)

Register R3 contains the digits 00CD0. Digit C is 1 if a valid REFSMMAT is stored, and 0 if no valid REFSMMAT is stored. Digit D is 1 if a valid LM attitude is stored, and 0 if no valid attitude is stored. If neither a valid REFSMMAT nor a stored LM attitude is available, the astronaut must select AT-2 or -3. The computer flashes VERB 05 NOUN 09 and stores alarm code 00701 if both C and D are 0 and the astronaut chooses AT-0 or AT-1.

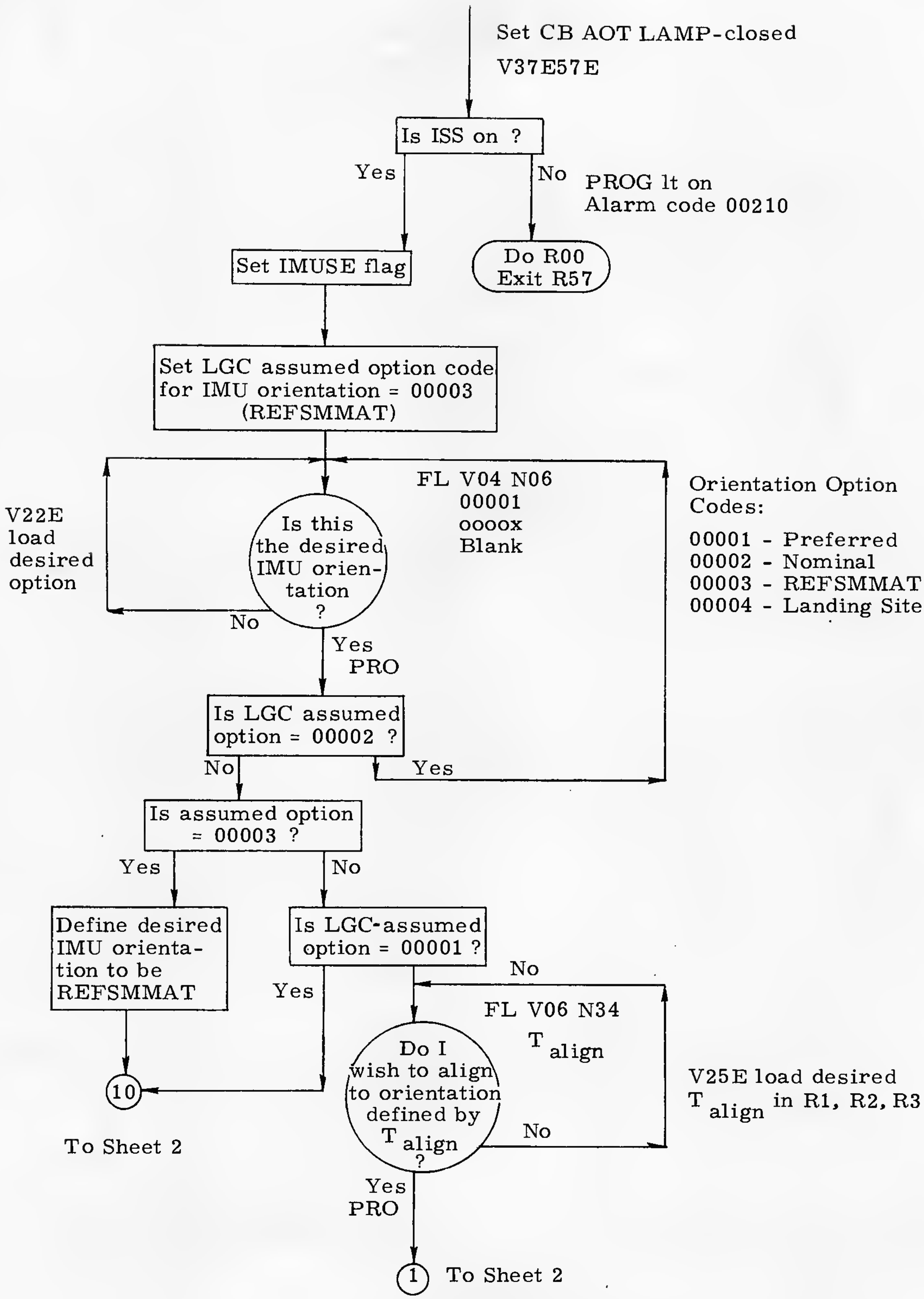


Figure 7.3.3-2. Lunar-surface Alignment Program (LM P57) (Sheet 1 of 7)

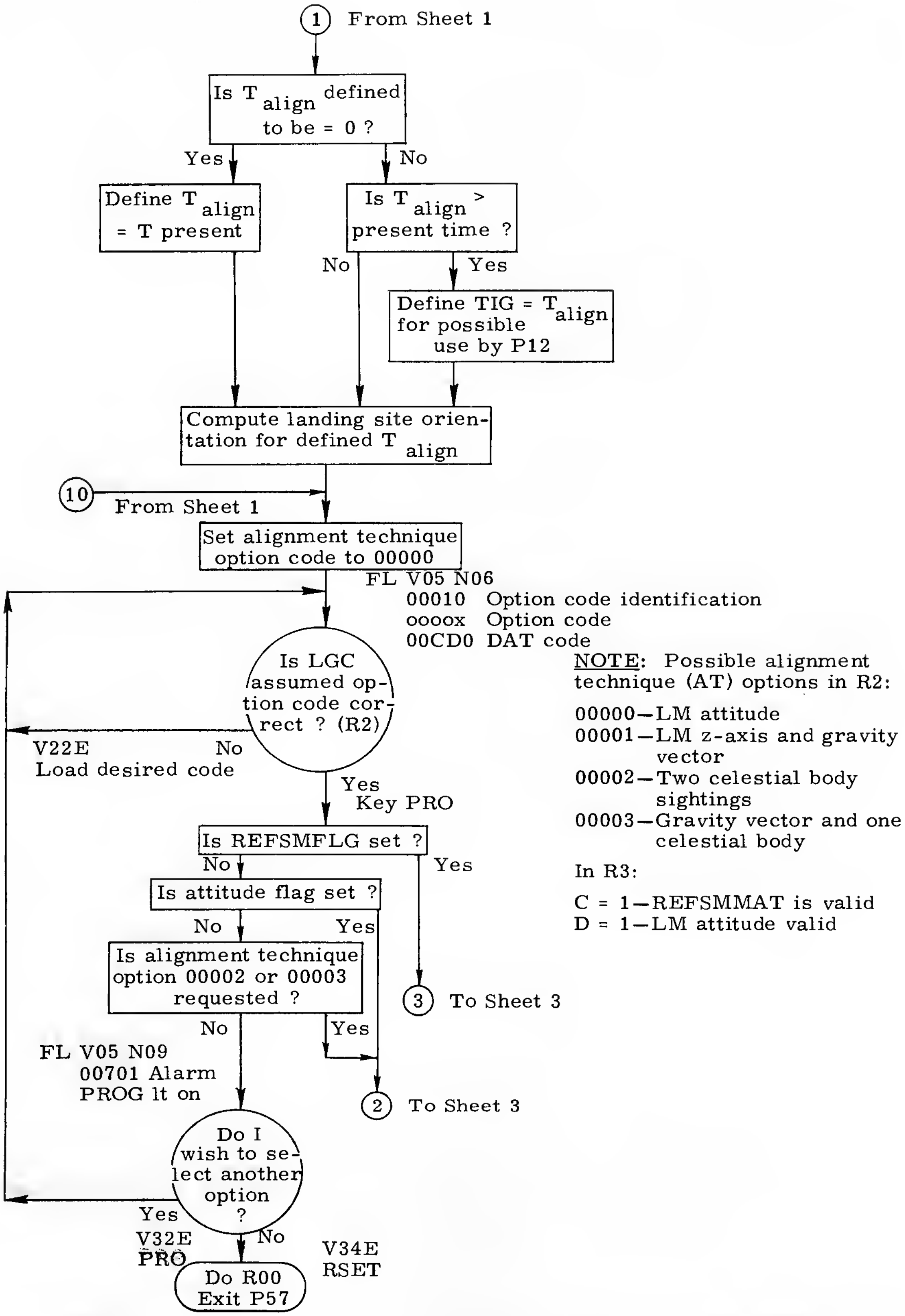


Figure 7.3.3-2. Lunar-surface Alignment Program (LM P57) (Sheet 2 of 7)

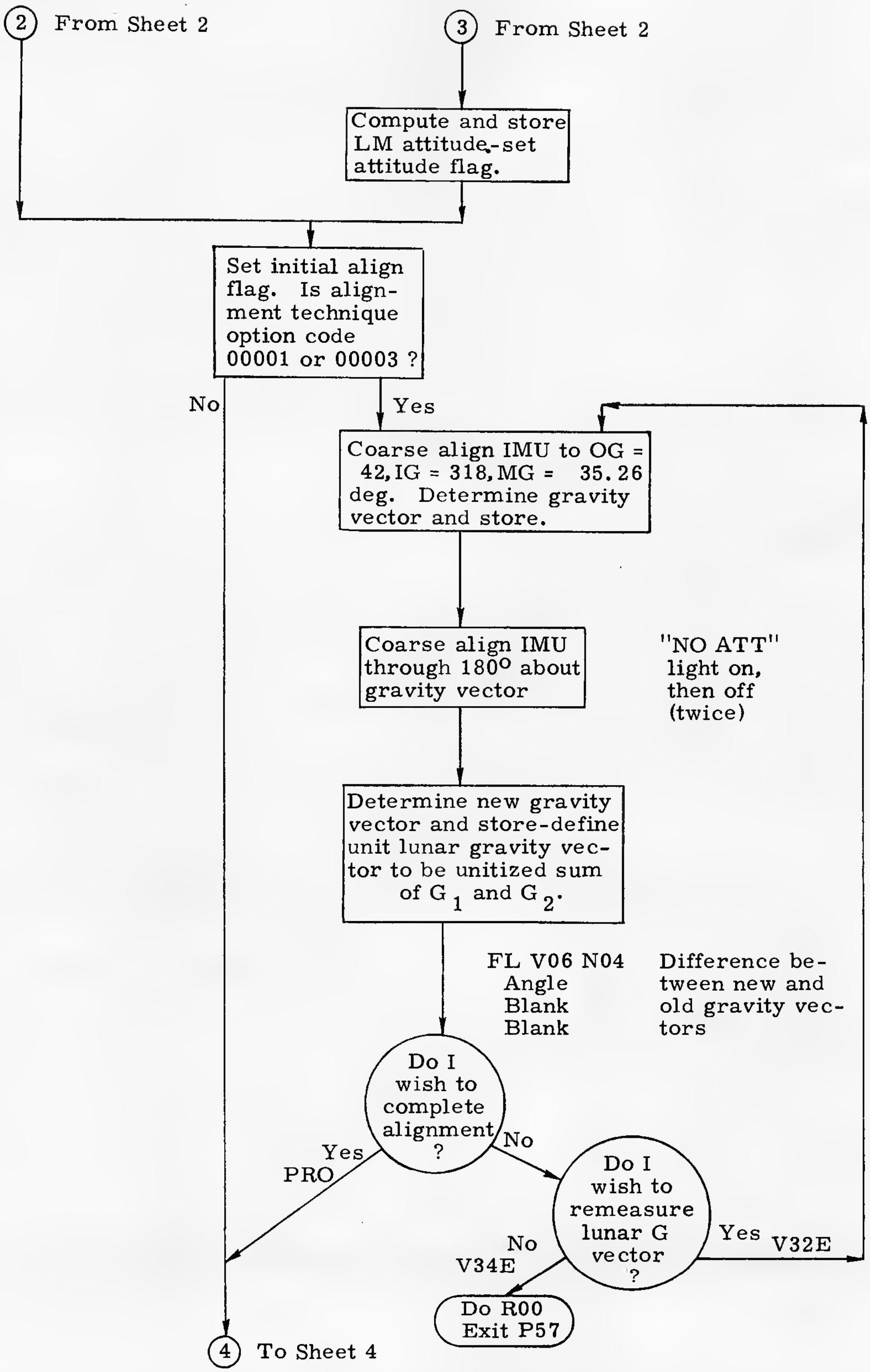


Figure 7.3.3-2. Lunar-surface Alignment Program (LM P57) (Sheet 3 of 7)

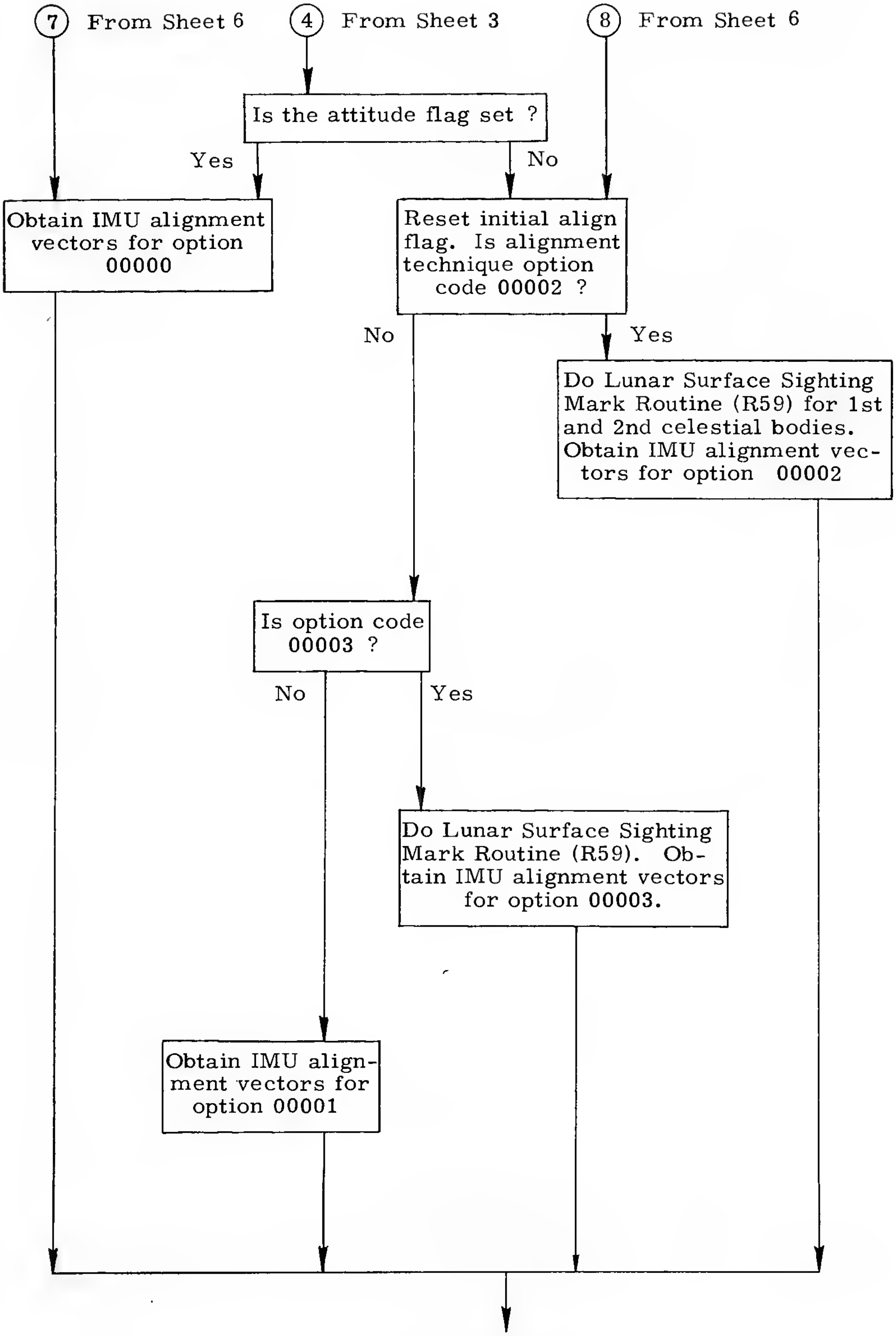


Figure 7.3.3-2. Lunar-surface Alignment Program (LM P57) (Sheet 4 of 7)

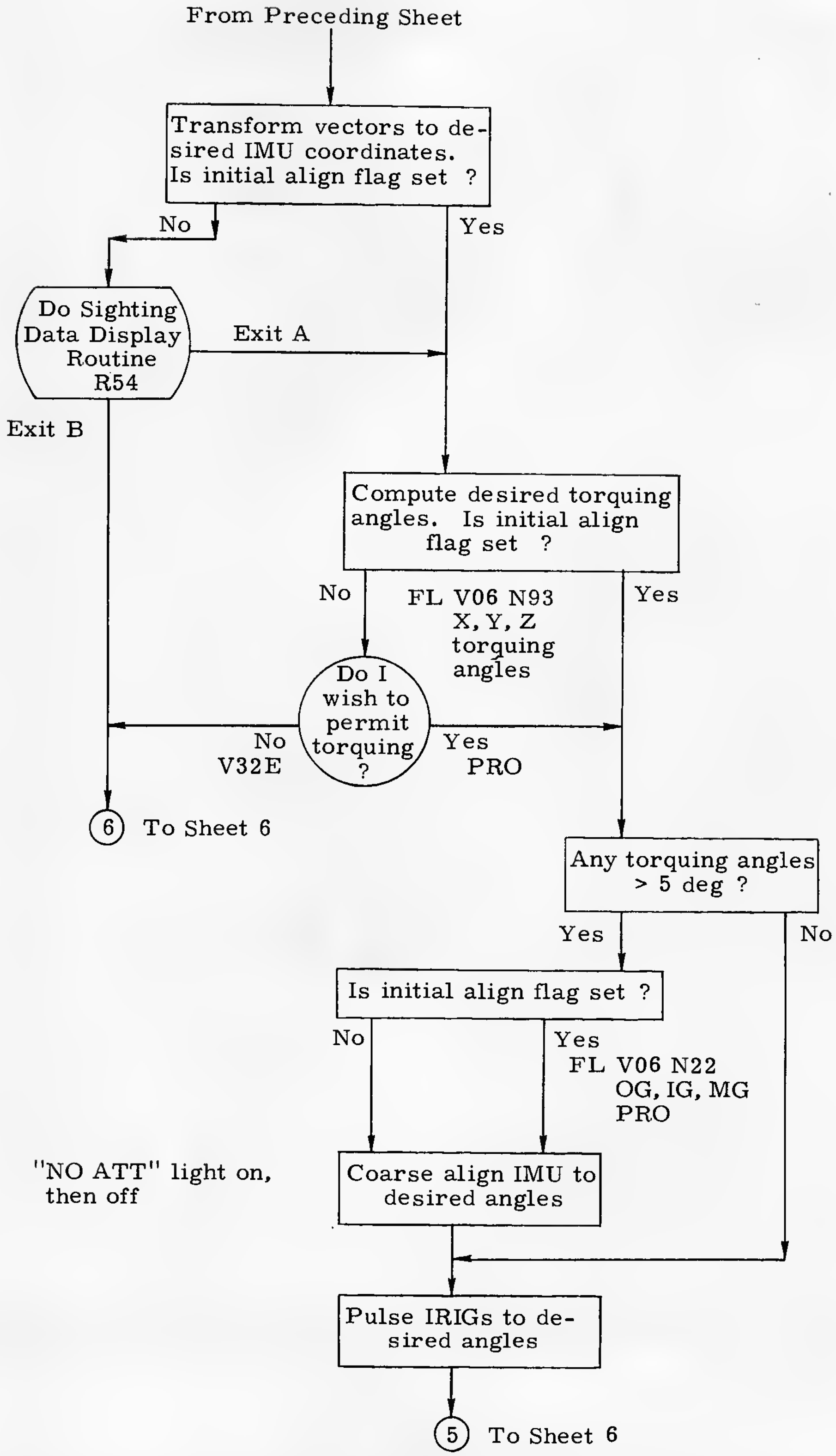


Figure 7.3.3-2. Lunar-surface Alignment Program (LM P57) (Sheet 5 of 7)

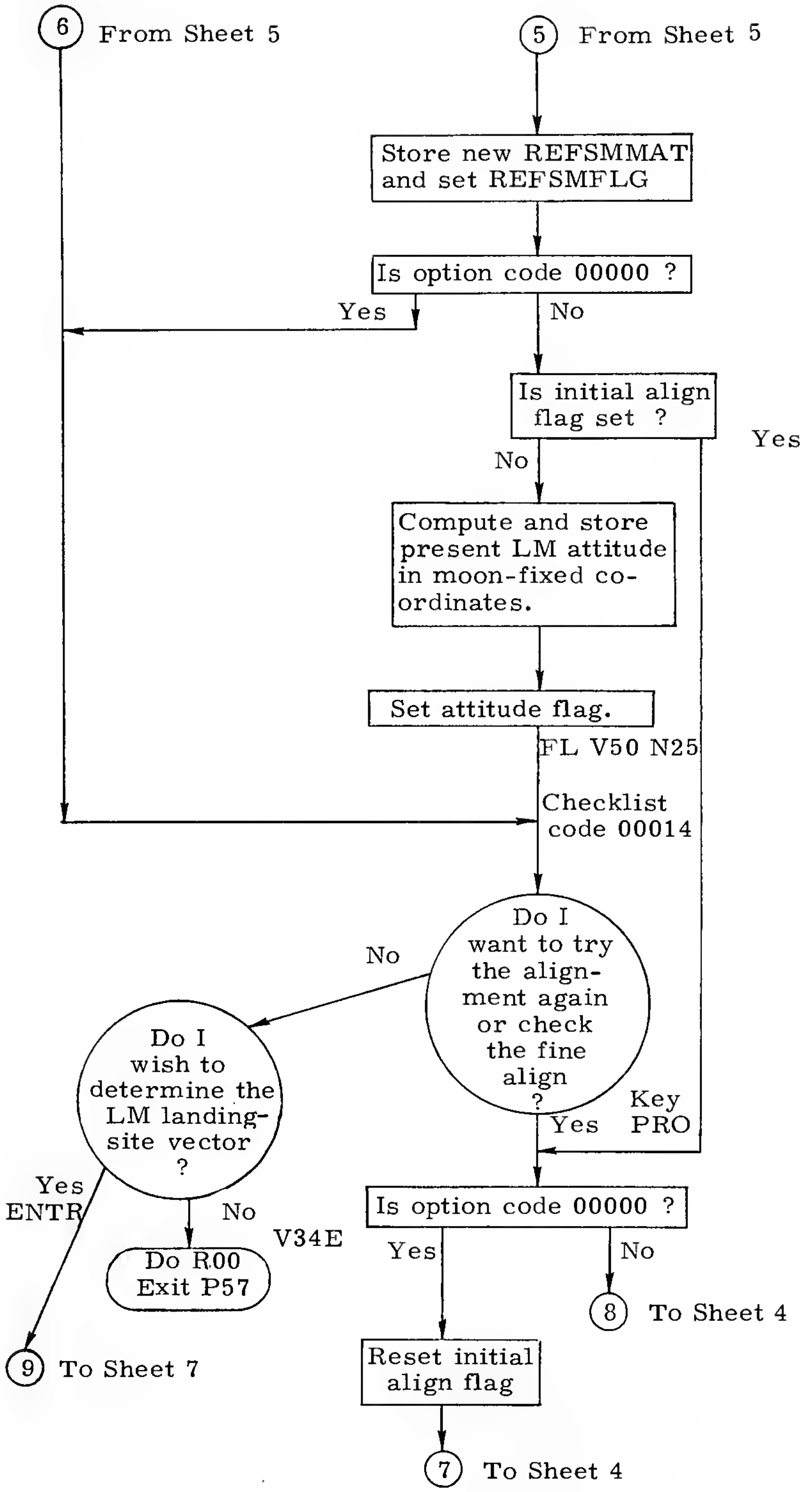


Figure 7.3.3-2. Lunar-surface Alignment Program (LM P57) (Sheet 6 of 7)

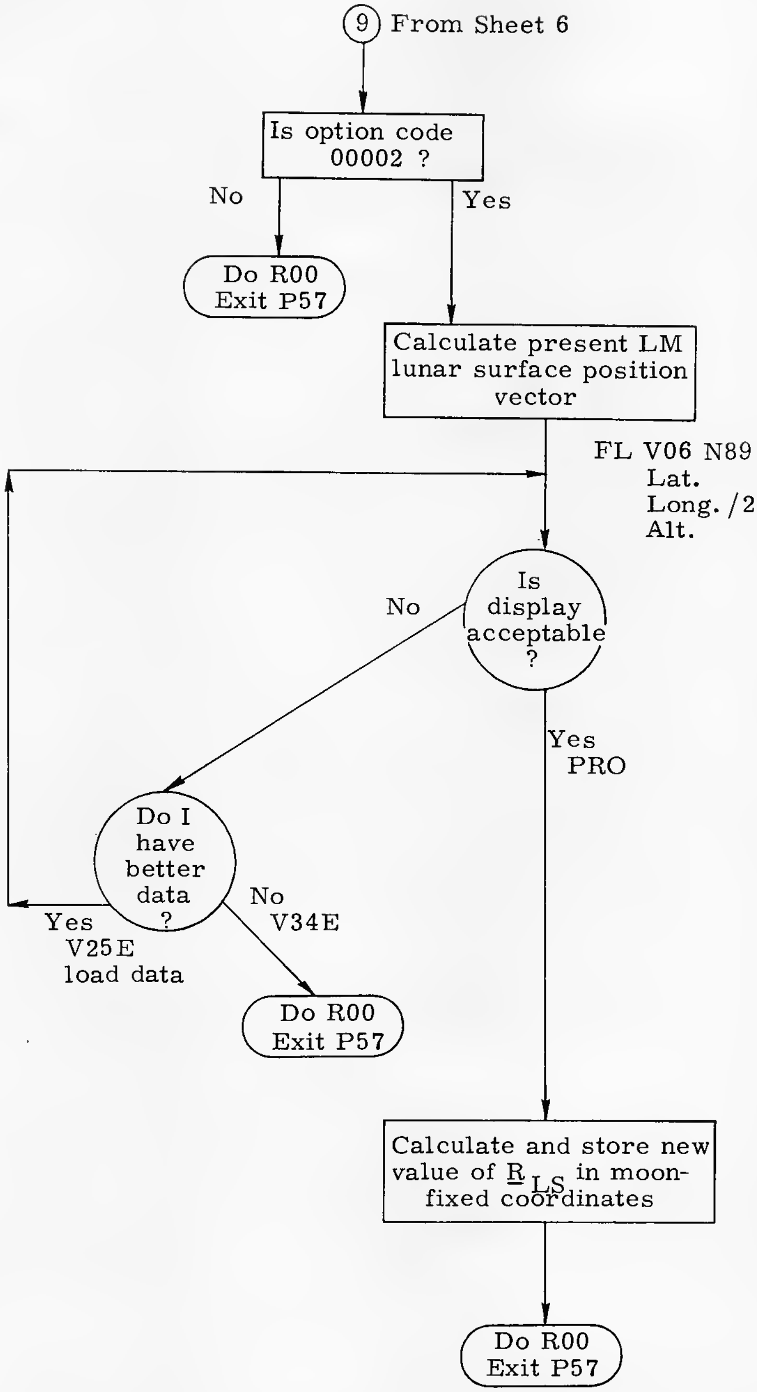


Figure 7.3.3-2. Lunar-surface Alignment Program (LM P57) (Sheet 7 of 7)

The astronaut can reload R2 via VERB 22 ENTR or approve the display by PRO. If a valid REFSMMAT is stored, the LGC then computes and stores the present LM attitude. P57 next performs an initial alignment to the desired orientation (paragraph 7.3.3.4.3 below). If the astronaut chose AT-1 or -3, the LGC first measures the gravity vector, then performs the initial alignment.

7.3.3.4.2 Gravity Vector Determination.—To measure the direction of the gravity vector, the LGC first orients the stable member to the following gimbal angles: outer gimbal = 42 deg; inner gimbal = 318 deg; middle gimbal = 35.26 deg. The NO ATT light is on while the stable member is coarse-aligned to these angles. The computer reads the PIPAs to determine a half-unit gravity vector in navigation-base coordinates, and calculates the gimbal angles required to rotate the stable member 180 deg about the gravity vector. The LGC next coarse aligns the stable member to the new angles, reads the accelerometers again, calculates another half-unit gravity vector, and calculates the unitized sum of the two measured gravity vectors. The resultant gravity vector is stored.

P57 then flashes VERB 06 NOUN 04. R1 displays the angle between the present and previously defined gravity vectors.* If this display is unsatisfactory to the astronaut and he wants to remeasure the gravity vector, he keys VERB 32 ENTR. A VERB 34 ENTR terminates P57 without saving the gravity vector just computed. If VERB 06 NOUN 04 is satisfactory, the astronaut keys PRO. P57 stores the gravity vector and performs an initial alignment to the desired orientation.

7.3.3.4.3 Initial Alignment.—For any alignment technique chosen by the astronaut, P57 performs an initial alignment of the stable member to the desired orientation, using REFSMMAT, if valid, and stored attitude information. (If no valid REFSMMAT or LM attitude is stored, P57 bypasses the initial alignment.) Using the LM Y- and Z-axes both in present and in desired stable-member coordinates, P57 calculates the torquing angles corresponding to the desired stable-member orientation. If the torquing angles are greater than 5 deg, the LGC flashes VERB 06 NOUN 22 and displays the calculated outer-, inner-, and middle- gimbal angles in R1, R2, and R3, respectively. When the astronaut keys PRO, the computer coarse-aligns the

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*If P68 was completed earlier and P57 performed for the first time, the LGC assumes that the previously defined gravity vector is parallel to the LGC-navigated $\underline{R}_{LS}$. Therefore, when P57 is performed for the first time after P68, this display contains the angle between the LGC-navigated $\underline{R}_{LS}$ and the gravity vector. The astronaut then has an indication of how much the landing-site coordinates can be expected to change when a subsequent P57 AT-2 is performed.

stable member to the displayed angles. After coarse-alignment, the LGC automatically trims out the coarse-alignment inaccuracy by pulse torquing. (If all required gimbal-angle changes are less than 5 deg, VERB 06 NOUN 22 and the coarse-align mode are bypassed; the LGC torques the gimbals to the desired angles.) P57 then stores the new REFSMMAT representing the new stable-member orientation. If the astronaut chose AT-0, the DSKY next flashes VERB 50 NOUN 25, checklist code 00014 ("Please perform fine-alignment"), as described in paragraph 7.3.3.4.8 below. For AT-1, P57 performs the alignment vector calculations in paragraph 7.3.3.4.7.

7.3.3.4.4 Lunar Surface Sighting Mark Routine.—If the astronaut selected AT-2 or -3, P57 calls the Lunar Surface Sighting Mark Routine (R59, Figure 7.3.3-3) after the initial alignment. If no valid REFSMMAT is stored, R59 immediately calls the AOT Mark Routine (R53, paragraph 7.3.3.4.5). If a valid REFSMMAT is stored, R59 flashes VERB 01 NOUN 70 requesting the astronaut to load the identification code for the celestial body used in the upcoming sighting.* When the astronaut finds a target, he can reload the celestial-body information by VERB 21 ENTR or approve the displayed values by PRO. R59 then calls the Celestial Body Definition Routine (R58, Figure 7.3.3-4) to obtain the stored LOS vector for the celestial body indicated in VERB 01 NOUN 70.

If the target is a star, R58 obtains its basic-reference vector from storage and returns control to R59. If the target was the sun, earth, or moon, R58 calculates the body's basic-reference vector and exits to R59. If the target is a planet, the DSKY flashes VERB 06 NOUN 88 and displays the x-, y-, and z-components of the LGC-assumed target basic-reference vector. The astronaut keys VERB 25 ENTR to reload the vector components or keys PRO to approve the displayed values. R58 then exits to R59.

R59 uses the celestial-body basic-reference vector to calculate the target LOS in navigation-base coordinates. If the target LOS is within 30 deg of the AOT optic axis for any detent, the LGC calculates the cursor and spiral angles that locate the target within the field-of-view. These angles and the required detent code are displayed under flashing VERB 06 NOUN 79. If the display is acceptable to the astronaut, he keys PRO; R59 then calls the AOT Mark Routine (R53). If the display is unsatisfactory, the astronaut keys VERB 32 ENTR to recycle to the flashing VERB 01 NOUN 70 display at the beginning of R59.

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*R59, unlike R51, does not find targets for the astronaut.

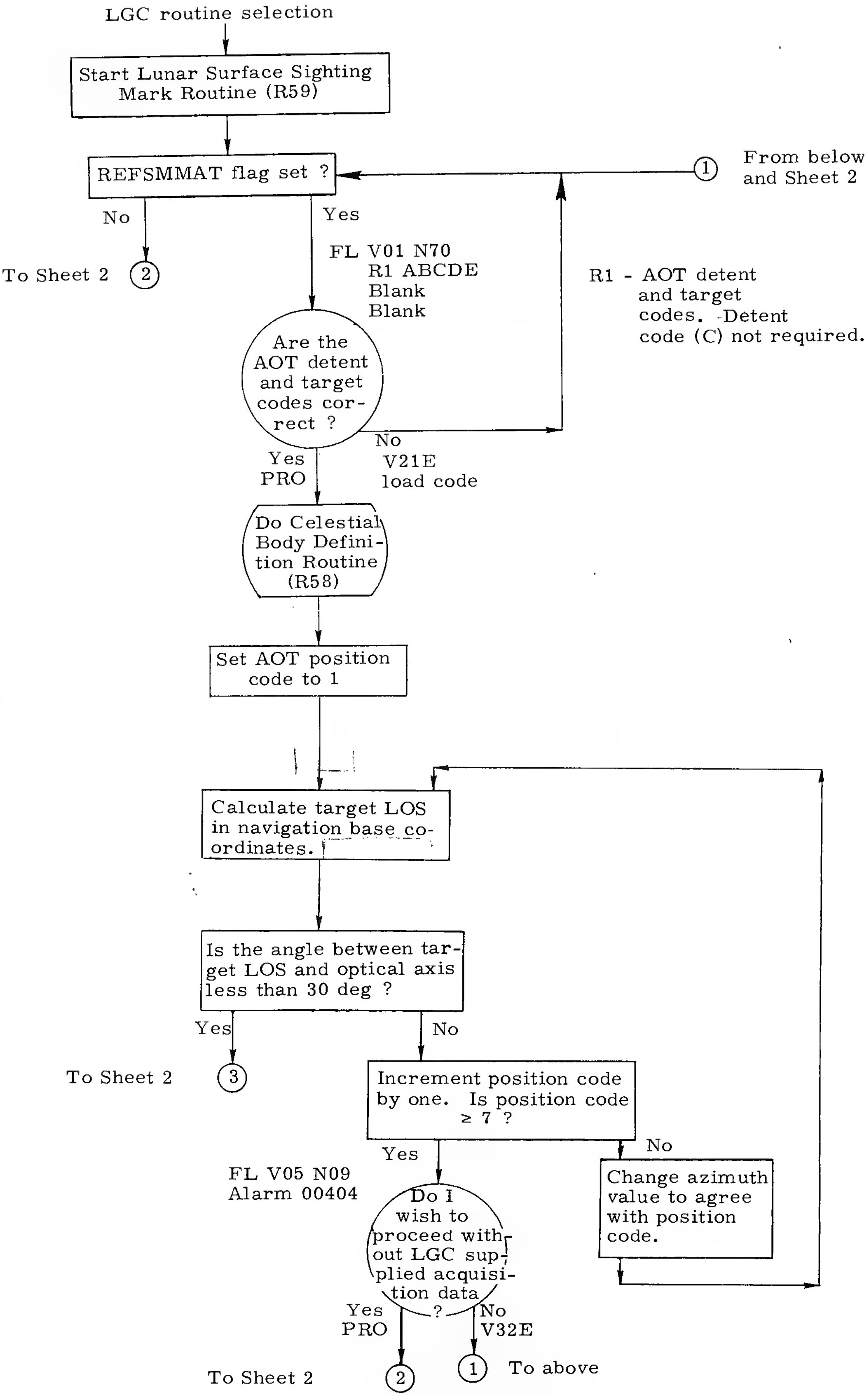

Figure 7.3.3-3. Lunar-surface Sighting Mark Routine (LM R59) (Sheet 1 of 2)

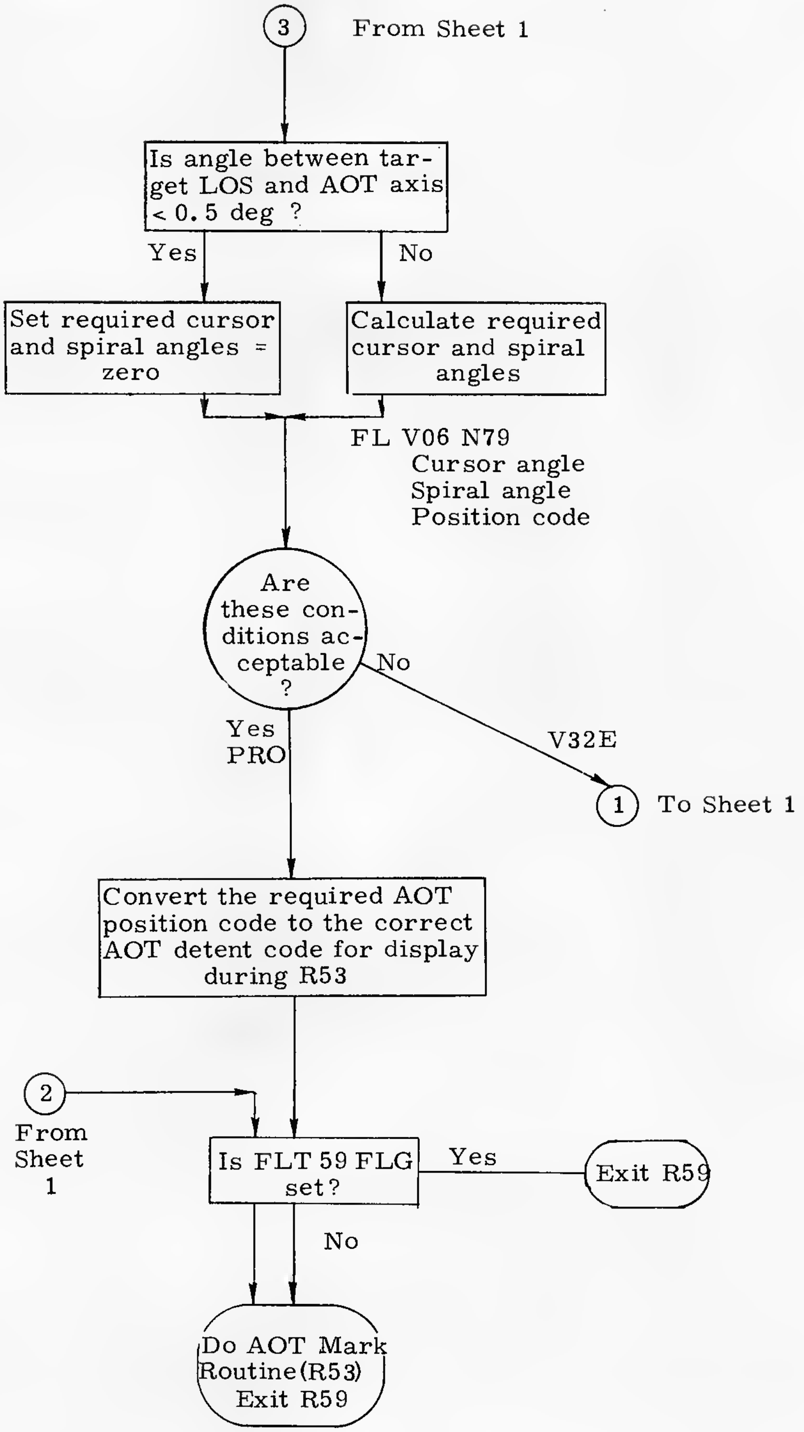

Figure 7.3.3-3. Lunar-surface Sighting Mark Routine (LM R59) (Sheet 2 of 2)

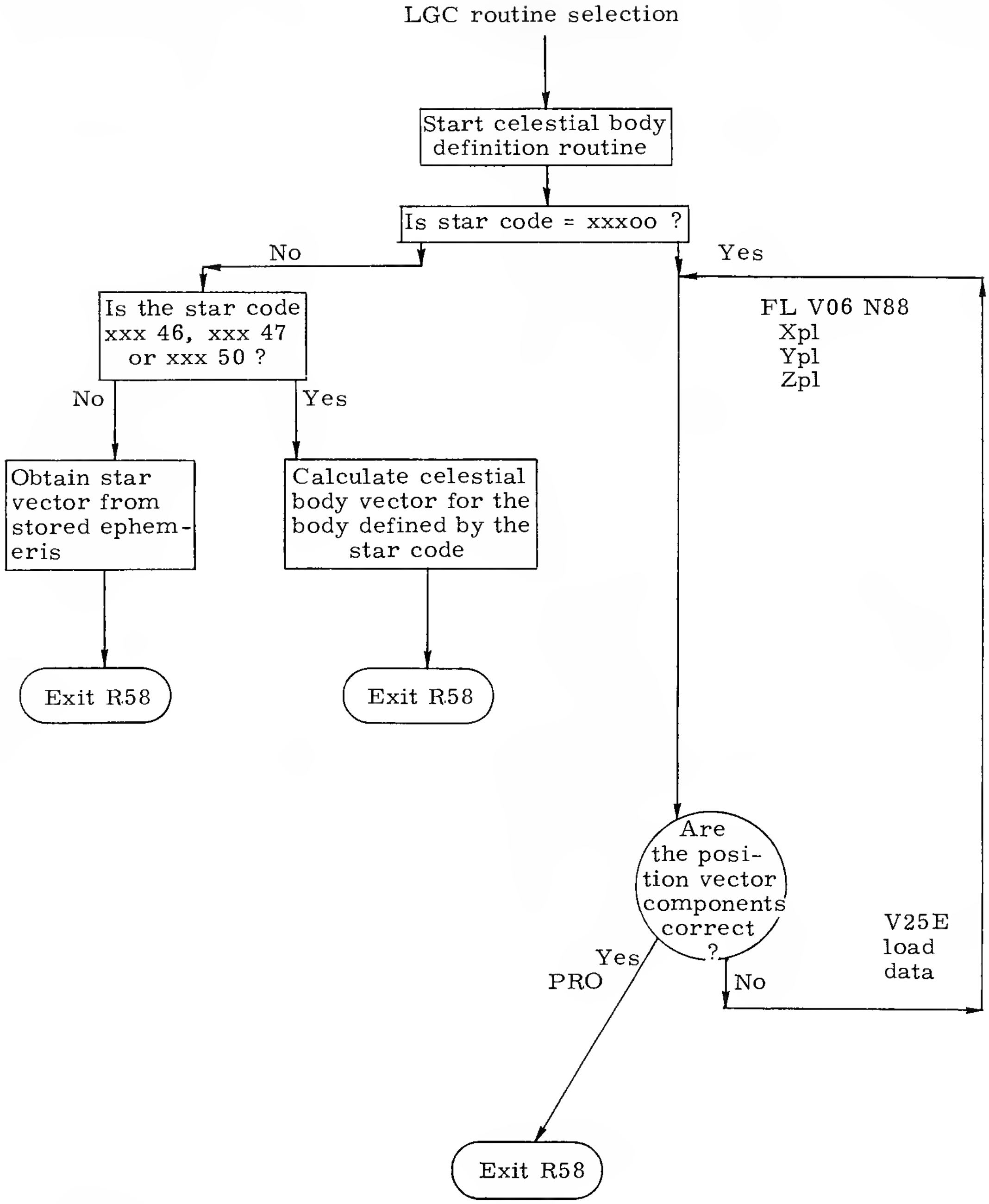

Figure 7. 3. 3-4. Celestial Body Definition Routine (LM R58)

If the computer determines that the celestial body cannot be acquired within 30 deg of the optical axis of any AOT detent, then the flashing VERB 06 NOUN 79 is bypassed. Instead, the astronaut sees flashing VERB 05 NOUN 09 with program alarm code 00404. The astronaut can then either (a) use VERB 32 ENTR to recycle to flashing VERB 01 NOUN 70 and find a new target, or (b) key PRO to go to R53 without the LGC-supplied cursor and spiral angles.

7.3.3.4.5 AOT Mark Routine.—After executing P59, the LGC enters the AOT Mark Routine (R53). R53 flashes VERB 01 NOUN 71, and R1 displays the AOT detent and celestial-body codes for the intended target. The astronaut either corrects the codes via VERB 21 ENTR or approves the display by keying PRO. If the astronaut approves AOT detent code 7 (backup optical system), he next sees flashing VERB 06 NOUN 87. R1 and R2 display, respectively, the azimuth and elevation of the backup optics LOS. These values can be either reloaded using VERB 24 ENTR or approved by a PRO.

The LGC next flashes VERB 52 NOUN 71 requesting the astronaut to perform a sighting mark using the cursor line of the AOT reticle pattern. A request for a sighting mark using the spiral line is indicated by flashing VERB 53 NOUN 71.

7.3.3.4.6 MARKRUPT Routine and AOT Sighting.—A cursor measurement is made by rotating the AOT reticle pattern until the cursor line is coincident with a star and depressing a MARK button. A spiral measurement is made by rotating the reticle pattern to bring the spiral line coincident with the star and depressing a MARK button. Up to 5 marks of each kind may be accumulated. Registers R2 and R3 maintain a count of the cursor and spiral marks. When the astronaut performs a cursor mark by depressing the MARK button under VERB 52 NOUN 71, VERB 21 NOUN 79 is displayed requesting the cursor angle load. When the astronaut loads the angle, VERB 06 NOUN 79 is displayed for data verification; a PRO causes the cursor data to be stored. VERB 52 NOUN 71 is redisplayed, requesting another cursor mark.

In the surface sighting technique the ENTR button not only controls the reject pointer as during the inflight sighting procedure, but is also the method by which the astronaut selects which measurement, cursor or spiral, he intends to perform. After sufficient cursor marks are accumulated under VERB 52 NOUN 71, the astronaut keys ENTR; the LGC displays VERB 53 NOUN 71 requesting spiral measurements. Depressing the MARK button under VERB 53 NOUN 71 causes VERB 22 NOUN 79 ("Please load spiral angle") to be displayed. When the spiral angle is loaded, VERB 06 NOUN 79 is displayed for data verification, and a PRO brings up VERB 53 NOUN 71

requesting another spiral mark. The astronaut may take cursor and spiral marks in any sequence by depressing the ENTR button to change the MARK VERB request from VERB 52 to VERB 53 or vice-versa.

A mark is not completed until a cursor or spiral angle has been loaded and verified by a PRO under VERB 06 NOUN 79. A MARK REJECT can only be performed under a MARK VERB display. Depressing the REJECT button will reject the mark indicated by the reject pointer in register R2 or R3, and the computer decrements the associated mark counter to reflect the REJECT action. The reject pointer can be moved from the cursor mark counter in R2 to the spiral mark counter in R3 or vice-versa by depressing the ENTR button under a MARK VERB display. The astronaut can continue to reject marks, if he desires.

The LGC accepts five cursor and five spiral marks or less. It is not necessary that the same number of cursor and spiral marks be made; however, the number of pairs of cursor spiral mark data that is used to compute and average LOS vectors will be equal to the least number of cursor or spiral marks made. After each mark the astronaut may take one of the following actions.

a. Continue marking on the same target (if less than five marks have been taken).
b. Key VERB 32 ENTR to throw away all data on the present target, select a new target, load the new celestial body code under flashing VERB 01 NOUN 71, and continue marking.
c. Key PRO to terminate marking when sightings are completed. R53 then calculates the target's LOS vector by averaging the vectors derived from the mark data.

The computation scheme used to compute the star vectors from data collected by the lunar-surface marking technique can reject mark data sets, i.e., CDU's, cursor and spiral, for a given mark. If any data is rejected during the LGC's celestial body-vector computation, the astronaut will see flashing VERB 50 NOUN 25, R1 = 00016 requesting additional marks. Register R2 contains the number of data sets rejected by the LGC. Data for a given sighting mark are rejected if the star is within 2 deg of the AOT optic axis or if the star lies on the edge of the AOT field-of-view greater than 28.5 deg from the AOT optic axis. Data are also rejected if more than 28 LGC iterations are required to converge to a solution or if the sign of the iteration step changes more than once. The following action is possible under R1 = 00016:

a. The astronaut can key PRO to continue with the alignment using the average LOS vector computed from non-rejected mark data.

b. The astronaut can key VERB 32 ENTR to reject all mark data accumulated for this sighting and start the sighting sequence at VERB 01 NOUN 71.

c. The astronaut can terminate the alignment program by keying in VERB 34 ENTR.

After R53 calculates the target's measured LOS vector, P57 calls the Celestial Body Definition Routine (R58) to obtain the stored (not measured) vector representing the target LOS in basic-reference coordinates.* If the astronaut selected AT-2, he must now find a second target and perform another set of sightings, starting with paragraph 7.3.3.4.4 above. For AT-3 alignments, only one set of celestial-body sightings is needed.

7.3.3.4.7 Sighting Data Display Routine.—For all alignment techniques, P57 calls the Sighting Data Display Routine (R54, Figure 7.3.3-5). R54 first calculates the angle between the alignment vectors using the stored (actual) values, then calculates the same angle using the measured values. The sighting-angle difference is displayed under flashing VERB 06 NOUN 05 and contains the following information:

a. AT-0—angle between LM Y- and Z-axes as measured in present stable-member coordinates, minus same angle as stored in desired stable-member coordinates.

b. AT-1—angle between gravity vector and LM Z-axis as measured in present stable-member coordinates minus angle between stored landing-site vector and LM Z-axis in desired stable-member coordinates.

c. AT-2—angle between two measured celestial-body LOS vectors in present stable-member coordinates, minus same angle from stored celestial body LOS in desired stable-member coordinates.

d. AT-3—angle between gravity vector and celestial body LOS measured in present stable-member coordinates minus angle between stored landing-site and celestial-body LOS vectors in desired stable-member coordinates. (Two or more AT-3 sighting-angle differences can be used by the ground to refine the knowledge of the true landing site.)

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*The Celestial Body Definition Routine is used both before and after the sightings are taken. R58 is called for the second time to work with the celestial body actually used by the astronaut, because he might have changed targets during the mark sequence.

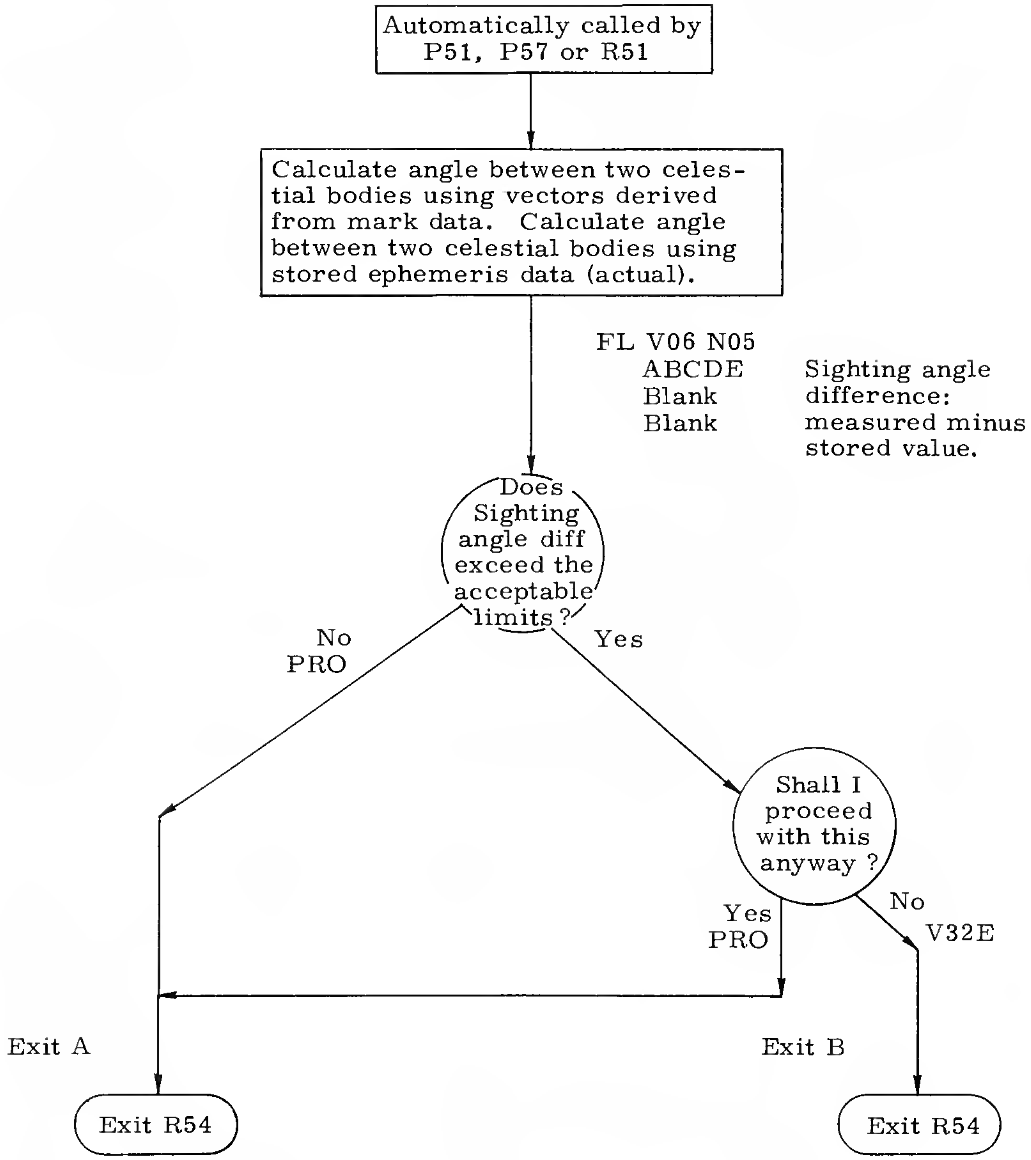

Figure 7. 3. 3-5. Sighting Data Display Routine (LM R54)

If the AT-2 sighting angle difference display is unacceptable to the astronaut, he keys VERB 32 ENTR. P57 then flashes VERB 50 NOUN 25, checklist code 00014 ("Please perform fine-align check," paragraph 7.3.3.4.8 below).

When the sighting-angle difference is acceptable, the astronaut keys PRO. P57 then (1) computes the gyro torquing angles required to align the stable member to the desired orientation and (2) displays the torquing angles under flashing VERB 06 NOUN 93. If the astronaut does not want to perform gyro torquing, he keys VERB 32 ENTR. P57 then flashes VERB 50 NOUN 25, 00014 (paragraph 7.3.3.4.8). When the astronaut approves gyro torquing, he keys PRO, and P57 torques the gyros through the required angles. (If any gyro torquing angle is greater than 5 degrees, the computer will first coarse-align, then gyro-torque the stable member to the desired orientation.) P57 stores the desired stable-member orientation in REFSMMAT and, for all options except AT-0, computes and stores the present LM attitude.

7.3.3.4.8 Fine-Align Check.—P57 flashes VERB 50 NOUN 25 and displays checklist code 00014 ("Please perform fine-alignment"). If the astronaut wants to repeat the measurements and calculations for the final alignment, he keys PRO. P57 then checks the alignment technique option code and performs the following:

a. AT-0—P57 performs the same calculations as for an initial alignment, except that the Sighting Data Display Routine (paragraph 7.3.3.4.7) is not bypassed.
b. AT-1—P57 obtains (1) the stored $\underline{R}_{LS}$ and Z-axis and (2) the measured gravity and Z-axis, then enters the Sighting Data Display Routine.
c. AT-2 and -3—P57 calls the Lunar Surface Sighting Mark Routine (paragraph 7.3.3.4.4).

All final alignments flash VERB 50 NOUN 25, 00014, when they are completed; the astronaut can repeat the final-alignment as many times as desired, or a VERB 34 ENTR at this display will terminate P57. For AT-2, an ENTR at checklist code 00014 will command P57 to compute and display the present landing-site coordinates.* The DSKY flashes VERB 06 NOUN 89 and displays the landing-site latitude, half-longitude, and altitude. The astronaut can respond to VERB 06 NOUN 89 as follows:

*A gravity vector must previously have been determined with AT-1 or AT-3 before a landing-site calculation is performed.

a. If the displayed data are unacceptable and the astronaut has better data (for example, data voiced from the ground), he can use VERB 25 ENTR to reload the landing-site coordinates.

b. If the displayed data are unacceptable and the astronaut has no better, he can key VERB 34 ENTR to terminate P57. The program will not change the old landing-site coordinates.

c. If the display is acceptable, the astronaut keys PRO. P57 then calculates R_{LS}, in moon-fixed coordinates, and stores it in place of the old value of R_{LS}. The LGC places the landing-site vector on downlink and P57 terminates automatically.

7.3.3.5 Program Alarms

The alarm codes that the astronaut might encounter during lunar-surface alignment are as follows:

a. Alarm 00111 indicates not enough marks taken to calculate a target vector. Reinitiate the mark sequence.

b. Alarm 00112 indicates a mark or mark reject was attempted, or if LGC received ROD input with Average-G off, while the LGC was not accepting these inputs. Control is automatically returned to the interrupted job. Key RSET and continue.

c. Alarm 00113 indicates a hardware or software failure caused R57 to be called unnecessarily. Control is automatically returned to the interrupted job. Key RSET, continue normal operation, and refer to backup procedures for partial computer failure.

d. Alarm 00115 indicates mark reject was entered but ignored by LGC. Continue normal operation.

e. Alarm 00207 indicates ISS turn-on not present for 90 sec. Key RSET and open the IMU OPR circuit breaker. Wait 3 minutes and perform ISS turn-on sequence. If alarm recurs and ISS warning light is off, continue normal operation.

f. Alarm 00210 indicates the IMU is not on. P57 terminates automatically. Perform the ISS turn-on sequence and, when the NO ATT light is extinguished, perform P57, AT-2 or -3 to calculate a valid REFSMMAT.

g. Alarm 00211 indicates gimbal angles are not within 2 deg of commanded position after coarse-alignment. To determine size of error, key VERB 06 NOUN 20 ENTR for display of present gimbal angles, and key VERB 06 NOUN 22 ENTR for desired gimbal angles. Continue the alignment and record the torquing angles. Then perform fine-align check.

h. Alarm 00217 can accompany alarm 00211 and indicates a bad return from ISS mode switching. Control is returned to P57 as usual. The bad return might be due to a power failure during coarse- or fine-alignment. Key RSET and perform alarm 00211 recovery procedures.

i. Alarm 00404 indicates the LGC-assumed celestial body is not visible for sightings in any detent. The astronaut can either (1) key PRO to flashing VERB 01 NOUN 71 and define new detent and celestial body codes, or (2) key VERB 32 ENTR to redefine celestial body and have LGC again compute required cursor angle, spiral angle, and position code.

j. Alarm 00701 indicates astronaut selected alignment technique option code 00000 or 00001, but P57 cannot continue because neither a valid REFSMMAT nor LM attitude is stored. Select another option code or terminate P57.

k. Alarm 31207 indicates no LGC VAC areas are available for storing mark data. The LGC performs a software restart to flashing VERB 01 NOUN 71, R53.

l. Alarm 31211 indicates an illegal interrupt of an extended verb already in progress. The LGC performs a software restart to flashing VERB 01 NOUN 71, R53.

7.3.3.6 Program Coordination and Procedures

Subsection 7.3 discusses the coordination of P57 with other computer activities during the LM lunar-surface mission phase. With the LGC and IMU powered up, the astronaut should perform the following activities before starting P57:

a. Turn on AOT heater at least 25 minutes before starting P57, to prevent fogging of AOT lens.

b. Turn on AOT lamp, but do not use both AC BUS A: AOT LAMP and AC BUS B: AOT LAMP at the same time.

c. Adjust the RETICLE BRIGHTNESS control.

d. When the astronaut performs P68 and sets the MODE CONTROL PGNS switch to ATT HOLD, the DAP will not fire the RCS jets when P57 reorients the stable member. Before performing P57, check to ensure that the switch is set properly.

The accuracy of a P57 AT-3 alignment is affected by the angles between the measured gravity vector ($\underline{g}$), the LGC-stored $\underline{R}_{LS}$, and the celestial-body LOS. The relationship between these vectors has the following effects:

a. Any angular difference between $\underline{g}$ and the LGC-stored $\underline{R}_{LS}$ will not affect the ability to achieve a safe orbit as long as $\underline{g}$ represents the true local vertical and was measured accurately. However, any angular difference between $\underline{R}_{LS}$ and $\underline{g}$ can introduce an azimuth alignment error if the angle between the celestial body LOS and $\underline{g}$ is less than 90 degrees. The sensitivity of azimuth alignment to an angular difference between $\underline{R}_{LS}$ and $\underline{g}$ increases as the angle between the celestial body LOS and $\underline{g}$ decreases from 90 degrees. An azimuth alignment error affects only those activities that require an accurate knowledge of the stable member's orientation with respect to the Basic Reference Coordinate System.

b. If $\underline{R}_{LS}$ does not agree closely with $\underline{g}$, then the astronaut should not sight on a celestial body that is within less than roughly 40 degrees of $\underline{g}$. At a separation of less than 40 degrees, the azimuth alignment accuracy is adversely affected by the discrepancy between $\underline{R}_{LS}$ and $\underline{g}$. Even when $\underline{R}_{LS}$ is close to $\underline{g}$, the astronaut should not use an LOS that is within less than 20 degrees of $\underline{g}$.

c. Errors in celestial-body AOT sightings affect the azimuth component of the stable-member orientation, but not the pitch component. AOT error sources and their avoidance procedures are listed here:

(1) Reticle parallax error—use the eyecup, move the eye around to observe the extent of parallax, and attempt to center the eye. All celestial bodies should be within 22.5 deg of the center of the field-of-view; this limit can be located by noting that the spiral intersects the reticle crosshairs at 0 deg, 7.5 deg, 15 deg, 22.5 deg, and 30 deg off-axis (refer to Figure 7.3.3-6).

(2) Focussing (celestial-body blurring) error—with the reticle lighting off, focus the eyepiece for the best star image at or near the center of the field-of-view, and use only the minimum required reticle brightness.

(3) AOT detent calibration—the rear detents are mathematically extrapolated from the measured front detent calibration. This adds roughly 1 arc-min uncertainty to the sighting. Use the front detents, if possible.

(4) Random sighting error—perform at least three cursor and three spiral marks. If time allows, five mark pairs are optimum.

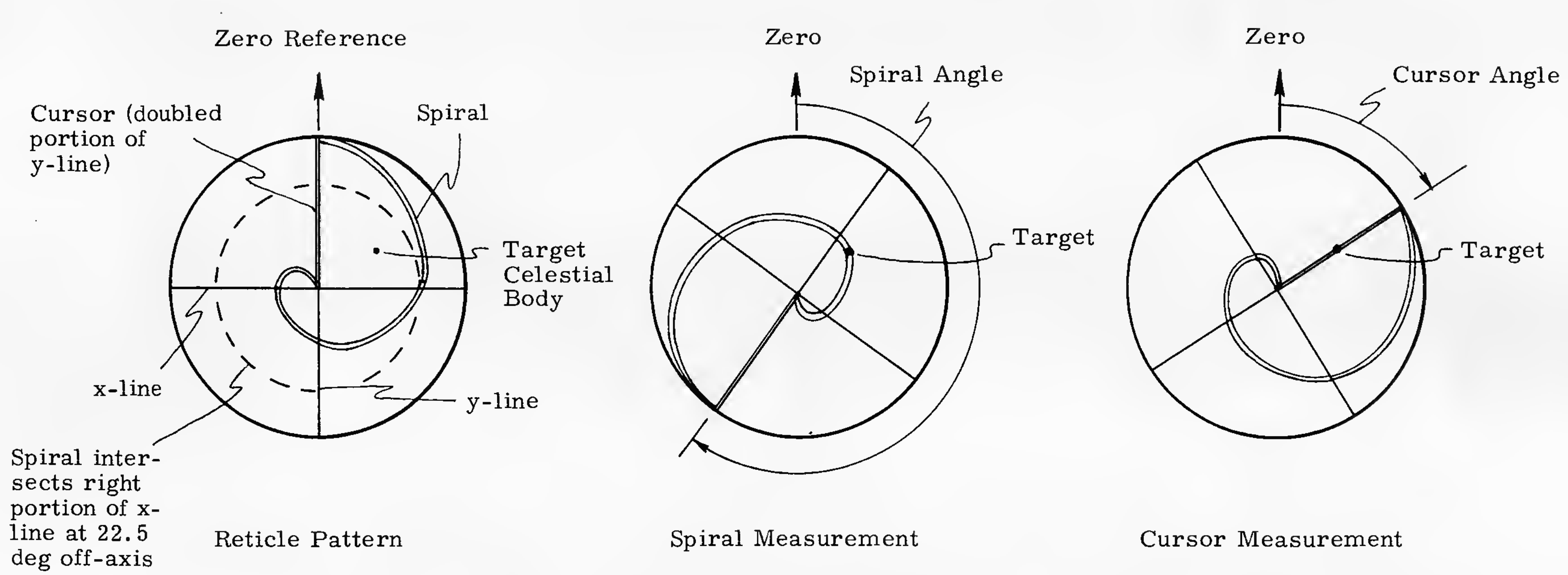

Figure 7.3.3-6. Alignment Optical Telescope Reticle Pattern

d. The accuracy of the pitch component of the alignment, which is critical for achieving a safe orbit, is affected only by the accuracy of the measurement of $\underline{g}$. This measurement is accomplished automatically by P57.

7.3.3.7 Restarts

P57 is restart-protected.

TABLE 7.3.3-II

SOURCES OF IMU ALIGNMENT VECTORS IN P57

Alignment Technique	Sources of IMU Alignment Vector			
	Basic Reference Coordinate System		Present IMU Stable Member Coordinate System	
	$\underline{S}'_A$	$\underline{S}'_B$	$\underline{S}_A$	$\underline{S}_B$
0	LM Y-axis stored in MFCS	LM Z-axis stored in MFCS	Present LM Y-axis	Present LM Z-axis
1	Landing Site stored in MFCS	LM Z-axis stored in MFCS	Gravity Vector Determination Routine	Present LM Z-axis
2	One or more of the following: 1. LGC star catalog 2. Loaded by astronaut 3. Ephemeris (i.e., SUN, EARTH)		AOT Sighting	AOT Sighting
3	Landing Site stored in MFCS	Same as technique 2 above	Gravity Vector Determination Routine	AOT Sighting

SECTION 8.0

ENTRY/DESCENT

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SUBSECTION 8.1

INTRODUCTION

(TBD)

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SUBSECTION 8.2

CMC ENTRY

(TBD)

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8.3 LUNAR MODULE DESCENT AND LANDING

Subsection 8.3 describes the LGC programs and crew procedures that guide the LM from descent orbit to touchdown at the desired landing site. The presentation of the lunar landing activities is as follows:

paragraph 8.3.1—Sequence of Events
paragraph 8.3.2—LM Hardware, Displays, and Controls
paragraph 8.3.3—Procedures
paragraph 8.3.4—Program Alarms
paragraph 8.3.5—Guidance Cycle
paragraph 8.3.6—TLOSS

8.3.1 Sequence of Events

The LM crew uses four LGC programs during lunar descent:

Braking Phase Program (P63)
Approach (or Visibility) Phase Program (P64)
Landing Phase (Rate-of-Descent) Program (P66)
Landing Confirmation Program (P68).

P63, P64, and P66 form a sequence of programs that controls the LM trajectory from descent orbit to touchdown. Table 8.3-I lists, for illustrative purposes, approximate times of various phases in the descent trajectory. At powered descent initiation (PDI), P63 starts the braking phase and guides the LM from descent orbit to high gate. The braking phase lasts for approximately 9 min. At P63 terminus, P64 starts and controls the LM during the time that the landing site is visible, until low gate is reached at an altitude of 200 feet and a descent rate of 5 fps. The visibility phase lasts for about 2 min.

The astronaut can select P66, the Landing Phase Program, before low gate if he desires. If he does not, P66 starts automatically at low gate, nulls the horizontal components of the LM velocity, and maintains the descent rate commanded by the astronaut. At touchdown, the astronaut disarms the descent propulsion system (DPS) and calls P68, the Landing Confirmation Program. P68 terminates the landing guidance calculations and initializes the LGC for lunar surface operations.

LGC programs operate during landing as follows:

TABLE 8. 3-I.

TIMELINE OF TYPICAL DESCENT TRAJECTORY*

Event	Time After DPS Ignition (min:sec)	Altitude (ft)	Vertical Velocity (ft/sec)	Horizontal Velocity (ft/sec)	Angle between +X Axis and Horizontal (deg)
DPS to full throttle	00:26	51, 556	-7	5550	-5
DPS throttle down	07:38	12, 100	-92	1000	+26
High gate	09:14	7, 450	-164	300	+33
Low gate	11:16	193	-5	7	+80
Touchdown	12:12	14	-3	0	+90

*For illustrative purposes only. Consult flight plan for nominal trajectory for each mission.

1. Braking Phase Program (P63).—The P63 guidance equations are designed to guide the LM from orbit to the beginning of visibility conditions along a trajectory that is economical in the use of DPS fuel. At the start of P63, an ignition algorithm uses the LM state vector and a pre-stored nominal state vector at the start of full throttle to calculate the time when the DPS must be commanded to full throttle. Before ignition, the program aligns the LM X-axis with the required thrust orientation.

The LGC commands RCS ullage, DPS on, and throttle-up at the appropriate times. The landing radar should acquire the lunar surface during P63 at 35,000 to 40,000 ft altitude.

The computer yaws the LM to an attitude that allows the landing radar to acquire the lunar surface if the LM is not in the required attitude by the time it reaches 30,000 ft altitude. When the astronaut determines that the radar is returning valid data, he commands the LGC to update the inertially-derived state vector with radar measurements of altitude and velocity.

During P63, the following control modes are available to the astronaut:

Attitude (PGNS MODE CONTROL switch)	AUTO.—The digital autopilot maneuvers the LM to follow the commands issued by the guidance equations. Above 30,000 ft, the astronaut can use the ACA to yaw the LM about the thrust axis (X-axis override). Below 30,000 ft in AUTO, the LGC inhibits X-axis override and yaws the LM to a windows-up attitude.
	ATT HOLD.—The autopilot maneuvers LM to follow manual commands. The astronaut must use the FDAI error needles to steer along the required trajectory.
Throttle (THR CONT switch)	AUTO.—Both LGC and manual throttle commands are fed to the DPS. Descent engine receives throttle commands proportional to sum of LGC and manual throttle signals.
	MAN.—Only manual throttle signals are fed to DPS. The throttle command decreases when THR CONT is switched from AUTO to MAN and rises when switched from MAN to AUTO, unless LGC is supplying zero throttle-command voltage. Astronaut can instruct computer to display the LGC desired throttle command on the DSKY (VERB 16 NOUN 92 ENTR).

2. Visibility (or Approach) Phase Program (P64).—P64 is designed to guide the LM from high gate to low gate while maintaining the LM within an attitude range that allows the crew to view the landing site through the forward windows. Shortly after the beginning of the visibility phase, the LGC identifies the landing site for the astronaut as follows: (a) the LGC orients the LM about the thrust axis such that the landing site lies along the reticle line of the landing point designator (LPD) fixed to the commander's window (Figure 8.3-1); (b) the DSKY displays the value of the angle along the LPD reticle that corresponds to a line of sight from the astronaut's eye to the landing site. If the current P64 landing site appears unsatisfactory or does not coincide with the desired site, the astronaut can retarget the LGC to a new landing site by keying PRO on the DSKY and using the ACA in PGNS AUTO mode. The LGC interprets ACA pitch and roll inputs as landing-site redesignations along the ground track and crossrange, respectively. (In AUTO, P64 does not respond to ACA yaw inputs.) The computer steers the LM to the new landing site and displays the revised LPD angle. Thus in PGNS AUTO, the astronaut has continual manual steering by incrementally shifting the point on the lunar surface where the LM will automatically land. PGNS ATT HOLD and throttle control modes are the same in P64 as in P63.

3. Landing Phase (ROD) Program (P66).—The astronaut can call P66 at any time during the landing by setting PGNS MODE to ATT HOLD and actuating the ROD switch. In P66, the LGC or astronaut must reduce the vehicle's horizontal velocity to zero and maintain a small rate of descent until touchdown. After touchdown, the astronaut disarms the DPS and keys PRO to stop the RCS jets. The LGC controls the LM horizontal motion independently of the vertical motion. The astronaut can use any combination of the following horizontal and vertical control modes:

Horizontal; either

AUTO.—The LGC controls the LM attitude, directing the thrust vector so as to null the LM's horizontal velocity.

or

ATT HOLD.—The astronaut uses the ACA and the DSKY and analog displays to null the horizontal velocity. FDAI error needles display difference between current attitude and attitude required to null horizontal velocity.

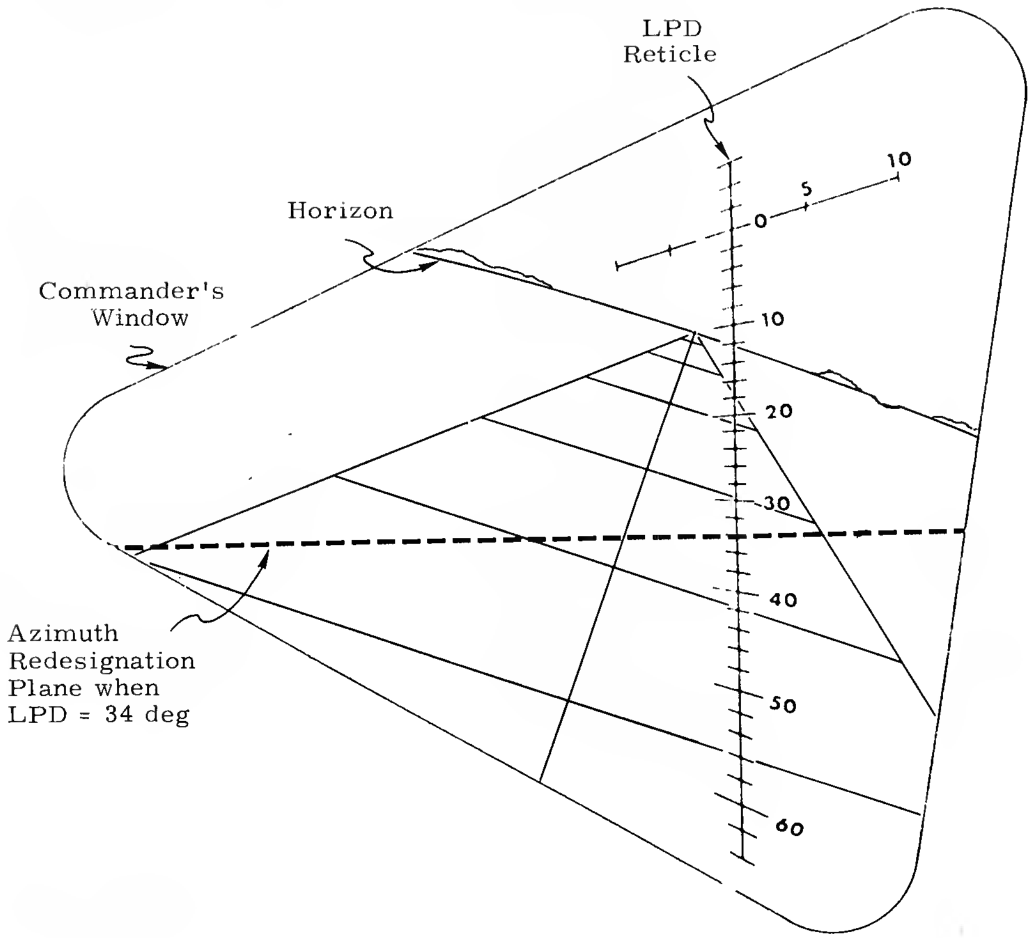

Figure 8.3-1. Redesignation Geometry at Large Roll Angle

Vertical; either

AUTO.—The LGC issues throttle commands to the DPS to maintain a constant rate of descent. The astronaut uses the ROD switch to increase or decrease the rate of descent that the LGC maintains, in 1 fps increments.

or

MAN.—The astronaut uses the manual throttle control, DSKY displays, and terrain observation to maintain a safe rate of descent. If the astronaut returns to AUTO, the LGC will maintain the rate of descent that exists at the time it regains control.

4. Landing Confirmation Program (P68).—The astronaut calls P68 after touchdown when he is sure that no immediate abort from the lunar surface is necessary. P68 terminates the landing guidance calculations and displays and stores the LM's position. P70 and P71 cannot be used for ascent after P68 is called; P12 must be used instead. Refer to subsection 3.3.

8.3.2 LM Hardware, Displays, and Controls

The following paragraphs describe some of the LM subsystems, displays, and controls that interface with the LGC and are used during landing.

8.3.2.1 Inertial Subsystem

The LGC must determine the position and velocity of the LM with respect to the landing site with sufficient accuracy to enable the guidance equations to compute a safe landing trajectory. The computer uses the difference between the current LM state vector and the desired terminal state vector to compute steering and throttle commands. During the landing, the Inertial Measurement Unit (IMU) measures the LM acceleration along the three stable-member axes. (Refer to subsection 7.1.) The LGC extrapolates the onboard state vector estimate every 2 sec by reading the accelerometers and integrating their outputs to compute new position and velocity vectors.

The landing programs operate on the assumption that the stable member is at one of the many possible orientations that it can assume, namely, the landing-site orientation. The stable-member X-axis is parallel to the landing-site radius vector ($\underline{R}_{LS}$) at the time of landing. The stable-member Z-axis is parallel to the CSM orbital plane, positive downrange, and the Y-axis completes the right-hand triad.

If the stable-member orientation is slightly different from the landing-site orientation but is accurately represented by REFSMMAT, a successful landing can still be accomplished. For example, slipping the landing by one orbit without realigning the stable member introduces an error of approximately 1 deg between the current landing site and the orientation represented by REFSMMAT. Simulations have shown that errors as large as 5 deg can be tolerated.

The IMU cannot provide information that would give position or velocity relative to an external body, such as the moon. Any position or velocity errors in the IMU-derived state vector will remain throughout the landing except for small variations due to IMU drift, and the LGC could attempt to land beneath or too far above the lunar surface. Even if the astronaut intervened, fuel usage could be so inefficient as to make a landing impossible. The LGC therefore uses the landing radar to correct the LM state vector relative to the moon.

8.3.2.2 Landing Radar

The landing radar (LR) measures the vehicle's altitude and velocity relative to the lunar surface. The LGC then changes the estimated state vector by comparing LR measurements with IMU-derived estimates of the same quantities. If the LR data passes certain tests (described in paragraph 8.3.5.1), the computer weights the differences between the LR and IMU data and incorporates the result into the state vector. The LR-data weighting functions are stored as precomputed, linear functions of altitude; the relative weight of LR data increases as altitude and velocity decrease.

The LR begins to supply data to the LGC at an altitude of approximately 30,000 to 40,000 ft, or shortly after the LM yaws to an attitude that enables the LR to acquire the lunar surface. The astronaut keys VERB 57 ENTR to enable LR state vector updates, and keys VERB 58 ENTR to exclude LR data. Before high gate, the LR antenna is in an orientation such that its centerline is tilted approximately 24 deg away from the LM X-axis (position 1). This allows the LR beams to contact the lunar surface at a reasonable angle because the LM is pitched up at a significant angle from the vertical. At high gate, the LGC realigns the antenna to orient the centerline parallel to the LM X-axis (position 2), because the LM X-axis is now more nearly vertical. The astronaut can also command these antenna positions (DES and HOVER, respectively) manually. The LR reacquires the lunar surface within 10 sec after antenna repositioning.

If by chance the LM velocity along the axis of one of the LR beams is nearly zero, the LR will lose its lock on the lunar surface and the LGC will illuminate the DSKY

ALT or VEL lights. The LR has been known to supply erroneous data just before this happens, but in general these data are excluded by software tests in the LGC. In flight, this phenomenon has not contributed any appreciable errors to the state vector. When the LM is near touchdown, the radar can track dust agitated by the descent engine. Therefore, to prevent erroneous LR data from degrading the state vector, the LGC automatically excludes radar updates when the LM reaches 50 ft altitude.

8.3.2.3 Controls and Analog Displays

Refer to Table 8.3-II for a description of selected displays and controls that the astronaut uses during landing.

8.3.3 Procedures

Table 8.3-III is a summary of descent DSKY procedures. The step number in the Table corresponds to the number in the amplified description presented here. Refer to paragraph 8.3.4 for description of program alarms.

1. The astronaut calls P52 about 70 min before ignition in order to realign the stable member to the landing-site orientation. He calls P63 about 5 min before the planned time of ignition by keying VERB 37 ENTR 63 ENTR, and, when the pre-ignition algorithm is completed, the DSKY displays the following ignition parameters:

   FL VERB 06 NOUN 61 (P63)

R1	-xxBxx	min, sec TG
R2	±xxBxx	min, sec TFI
R3	±xxxx.x	n.mi. CR

   where TG is the time of flight from ignition to high gate, TFI is the time from DPS ignition, and CR is the out-of-plane distance between the LM orbital plane and the current landing site.

   NOTE.—If the number of iterations performed by the ignition algorithm exceeds a specified maximum, the LGC turns on the PROG alarm light, stores alarm 01412, and continues the computation. Terminate P63 by keying VERB 96 ENTR or select a new program. Alarm possibly caused by bad uplink of state vector or landing site.

TABLE 8.3-II.
DISPLAYS AND CONTROLS ASSOCIATED
WITH THE LUNAR LANDING MANEUVER
(SHEET 1 OF 6)

Display/Control	Function	Remarks
ABORT Pushbutton	Actuated to initiate abort, using descent engine. Reset by pressing a second time.	If CHANBKUP Bit 1 = 1, astronaut must key VERB 37 ENTR 70 ENTR to perform DPS abort program. Use of ABORT button not required.
ABORT STAGE Pushbutton	Actuated to initiate abort, using only ascent engine. Reset by pressing a second time.	Actuation of switch arms ascent engine and performs staging. Astronaut keys VERB 37 ENTR 71 ENTR to call APS abort program if CHANBKUP Bit 1 = 1.
ALT and VEL DSKY Lights	Lights refer to LR altitude and velocity data, respectively. Lights flash when LR data fail reasonability test; on steadily when LR loses lunar-surface lockon.	
Attitude Control Assembly (ACA)	Either astronaut can command vehicle attitude changes manually, using his ACA. ACA is installed with its longitudinal axis approximately parallel to LM X-axis; vehicle rotations correspond to astronaut hand movements in operating ACA. Clockwise or counterclockwise rotation of ACA about its longitudinal axis commands vehicle yaw right or yaw left about LM X-axis. Forward or aft movement of ACA commands vehicle pitch down or pitch up, respectively, about LM Y-axis. Left or right movement of ACA commands roll left or roll right about LM Z-axis.	
Altitude/Range Indicator	Displays range/range rate data or altitude/altitude rate data as selected with RNG/ALT MON switch. Range/range rate data are from RR. Altitude/altitude rate data are from LR, PGNS, or AGS, as selected with MOD SEL switch. When LR data is selected, true altitude and altitude rate data are available from low-gate point to touchdown if LM X-axis is vertical. Before reaching low-gate point, only true altitude data are available from LR. When PGNS or AGS is selected, inertially derived altitude and altitude rate data are available for display.	
ATTITUDE CONTROL ROLL, PITCH and YAW switches	Used in conjunction with MODE CONTROL switches to establish attitude control in roll, pitch, and yaw. Normally these switches are set to MODE CONT while PGNS is in control.	
MODE CONT	Enables use of proportional mode of ACA when MODE control selector switch is set to ATT HOLD and PGNS is controlling. When MODE CONTROL selector switch is set to AUTO, LGC supplies attitude commands to maneuver LM. Under AGS control, function of MODE CONT positions are the same manner as when PGNS is controlling.	

TABLE 8.3-II.
DISPLAYS AND CONTROLS ASSOCIATED
WITH THE LUNAR LANDING MANEUVER
(SHEET 2 OF 6)

Display/Control	Function	Remarks
PULSE	Under PGNS control this position is inoperative. Under AGS control, the PULSE and DIR positions differ only in how RCS thrusters fire. When PULSE is selected, two jets in selected axis fire at constant pulsed rate as long as ACA is displaced more than one-fourth of full throw. PULSE and DIR positions provide open loop acceleration. Rates produced must be nulled to zero by inducing opposite acceleration command. Attitude is not maintained automatically until switch is returned to MODE CONT.	
DIR	Under PGNS control, when MODE CONTROL selector switch is set to ATT HOLD or AUTO, DIR mode can be used in any axis. Each switch must be set to DIR independently. Displacing ACA one-fourth of full throw causes continuous two-jet firing for selected axes. As in PULSE position, open loop acceleration is provided; it must be nulled in as during pulse operation.	
(Digital Autopilot) NO DAP Light	Illuminated when DAP is in idling or Minimum Impulse mode.	Selection of AGS will not cause light to go on.
DES ENG CMD OVRD switch	Supplies alternate source of 28-Vdc to descent engine shut-off valves.	Switch is used to keep valves open if descent engine control power fails.
ON	Applies 28-Vdc to descent engine shut-off valves.	Circuit is completed through normally closed contacts of ABORT STAGE switch.
OFF	Removes 28-Vdc from valves.	
DES RATE switch (R.O.D.)	Permits establishing LM rate of descent under PGNS control in fixed increments. Each switch actuation provides a discrete pulse, changing the rate of descent by 1 fps.	Response to switch commands can be monitored on the altitude rate scale of the Range/Range Rate; Altitude/Altitude Rate indicator and on DSKY.
+	Up deflection: Decreases rate of descent by 1 fps in the +X direction.	Plus sign denotes increase in engine thrust.
-	Down deflection: Increases rate of descent by 1 fps in -X direction.	Minus sign denotes decrease in engine thrust.
ENG ARM switch	Provides arming signals to engines.	Switch is spring loaded to center position. Regardless of switch setting, appropriate engine is armed if ABORT or ABORT STAGE switches are actuated.
ASC	Provides arming signal to enable firing of ascent engine and simultaneously signals LGC that engine is armed.	
OFF	Removes arming signal from engine valves and LGC.	
DES	Provides arming signal to enable firing descent engine and simultaneously signals LGC that engine is armed.	
ENG GMBL switch	Enables or disables engine gimbal drive capability.	Normally set to ENABLE. If ENG GMBL caution light goes on astronaut should consult malfunction procedures.
ENABLE	Gimbal trim signals are enabled to displace descent engine along Y-and Z-axes.	
OFF	Power to the GDA's is removed, disabling the gimbal drive capability.	

TABLE 8.3-II.
DISPLAYS AND CONTROLS ASSOCIATED
WITH THE LUNAR LANDING MANEUVER
(SHEET 3 OF 6)

Display/Control	Function	Remarks
Engine START Pushbutton	Permits immediate manual firing of descent or ascent engine, depending upon setting of ENG ARM switch.	When pressed, pushbutton remains pressed and illuminated (red). Actuation of either engine stop pushbutton interrupts override function, the engine stops, and the START pushbutton light goes out.
Engine STOP Pushbutton	Provide discrete stop signals to descent and ascent engines, independent of setting of ENG ARM switch, except when in abort sequence.	When pressed, pushbutton remains pressed and illuminated (red). It is reset by pressing it again.
ENGINE THRUST CONT switch		
THR CONT switch	Permits switching from automatic (LGC) throttle control to manual throttle control.	
AUTO	LGC command signals are summed with manual command signals from TTCA selected with MAN THROT switch for descent engine throttle control. TTCA always provides minimum 10% command; it cannot be set below this level.	When switch is set to AUTO, THRUST indicator displays LGC command plus 10% fixed bias. Manual throttle commands may be introduced by displacing active TTCA. This causes displayed % THRUST CMD to decrease because only LGC commands plus fixed bias are displayed.
MAN	Interrupts LGC throttle commands insuring that descent engine throttle is fed only by manual throttle command signals.	CMD THRUST indicator displays manual throttle commands. If CHANBKUP Bit 4=1. The MANUAL switch is ignored and software assumes AUTO Throttle.
Flight Director Attitude Indicator (FDAI)	Displays total vehicle attitudes, attitude rates and attitude errors, or vehicle attitude, attitude rates, and RR shaft and trunnion angles, depending on setting of RATE/ERR MON switch. Setting ATTITUDE MON switch selects PGNS or AGS as source of vehicle total attitude and attitude errors displayed on FDAI. Shaft and trunnion angles are displayed by pitch and yaw error needles, respectively, when RATE/ERR MON switch is set to RNDZ RADAR.	
GUID CONT switch	Selects PGNS or AGS for guidance control mode of LM.	
PGNS	Provides 800-cps power to activate ACA and TTCA, proportional rate command inputs to LGC from ACA, LGC engine on-off signals, descent engine gimbal trim command outputs from LGC, translation on-off commands from TTCA, enabling signals for primary preamplifiers of attitude and translation control assembly (ATCA), and applies follow-up signal to abort electronics assembly (AEA).	Switch is spring loaded to center (lock) position. When AGS mode is selected, PGNS remains operational. PGNS data can be displayed if desired.
AGS	Provides 800-cps power to activate ACA and TTCA, proportional rate commands to ATCA from ACA, AGS mode trim command, and enabling signals to the abort preamplifiers of ATCA.	
LDG ANT switch		
AUTO	Enables LGC to position LR antenna as function of mission phase.	
DES (cont.)	Drives antenna to first position used before hover point.	Because antenna cannot be driven to its first position by LGC and it is necessary to provide override of position drive signal if LR antenna interface fails, DES and HOVER positions are used.

TABLE 8.3-II.
DISPLAYS AND CONTROLS ASSOCIATED
WITH THE LUNAR LANDING MANEUVER
(SHEET 4 OF 6)

Display/Control	Function	Remarks
LDG ANT switch (cont.)		
HOVER	Drives antenna to its second position for final landing phase.	
LUNAR CONTACT Light	Both lights go on when prohe(s) on landing gear touches lunar surface, to indicate that descent engine should be turned off.	Light goes off when either Engine Stop switch is pressed.
MAN THROT switch	Selects thrust/translation controller for manual adjustment of descent engine thrust level, if corresponding THROTTLE-JETS control select lever is set to THROTTLE. This switch also routes manual throttle commands from controller to descent engine control assembly.	
CDR	Enables Commander's thrust/translation controller to adjust descent engine thrust level.	
SE	Enables LM Pilot's thrust/translation controller to adjust descent engine thrust level.	
MODE SEL switch	Selects radar or computer data for display on X-Pointer and Altitude/Range indicators.	Data from selected source are displayed on appropriate horizontal velocity indicator only when RATE/ERR MON switches are set to LDG RDR/COMPTR. Data from selected source are displayed on Altitude/Range indicators only when RNG/ALT MON switch is set to ALT/ALT RT.
LDG RADAR	Radar altitude, altitude rate, and forward and lateral velocity are displayed.	
PGNS	LGC-eomputed altitude, altitude rate, and forward and lateral velocity are displayed.	
AGS	AGS-computed altitude, altitude rate and lateral velocity are displayed.	
PGNS MODE CONTROL switch	Affects outputs of ACA's, TTCA's and LGC.	Switch is associated with ATTITUDE CONTROL switches and GUID CONT switch.
OFF	Establishes the following conditions: a) Limits operation of the ACA's to the hardover position, b) Enables two-jet direct attitude control in axis selected with ATTITUDE CONTROL switehes, c) Disables translation outputs of TTCA's and LGC attitude commands.	TTCA throttle commands are not affected. LGC engine-off signals are not enabled: engine must be manually turned off.

TABLE 8.3-II.
DISPLAYS AND CONTROLS ASSOCIATED
WITH THE LUNAR LANDING MANEUVER
(SHEET 5 OF 6)

Display/Control	Function	Remarks
PGNS MODE CONTROL switch (cont.)		
ATT HOLD	If PGNS control is selected, astronauts can command attitude rates proportional to ACA displacement, and attitude is held when ACA is returned to detent. When a programmed minimum impulse mode command (entered via DSKY) is in effect, moving ACA 1/4 of full throw in any axis commands a pulse to applicable RCS jets. No attitude or attitude rate stabilization is provided in this mode.	When ATTITUDE CONTROL switches are set to PULSE or DIR, following attitude command capabilities result: With GUID CONT switch set to PGNS and one or more ATTITUDE CONTROL switches set to PULSE, attitude hold mode is not affected. With GUID CONT switch set to PGNS and one or more ATTITUDE CONTROL switches set to DIR, ACA displacement of one-fourth of full throw causes continuous two-jet firing for selected axes, without rate feedback interfering with LGC command signals.
AUTO	When GUID CONT switch is set to PGNS, rate-compensated steering errors are generated by LGC and on-off commands are fed to jet drivers. RCS translation outputs of TTCA's are enabled.	TTCA and ACA hardover outputs are not affected. When one or more ATTITUDE CONTROL switches are set to PULSE or DIR, the following attitude command capabilities and limitations result. With GUID CONT switch set to PGNS and one or more ATTITUDE CONTROL switches set to PULSE, attitude hold mode is not affected. With GUID CONT switch set to PGNS and one or more ATTITUDE CONTROL switches set to DIR, conflicting commands from LGC result when ACA's are displaced one-fourth of full throw.
RNG/ALT MON switch	Selects display legend on Altitude/Range indicator and displays RR range/range rate data or LR or computer altitude/altitude rate data.	
RNG/RNG RT	RR range and range rate data are displayed on Altitude/Range indicator.	
ALT/ALT RT	Data from source selected with MODE SEL switch are displayed on Altitude/Range indicator.	
THRUST indicator	Displays descent engine chamber pressure, which corresponds to thrust on ENG scale (left pointer) and manual or LGC thrust commands to the engine on CMD scale (right pointer). Both scales read from 0% to 100%. Automatic or manual throttle commands can be displayed, depending on setting the THR CONT switch. The CMD (right) scale indicates 10% thrust command, even when engine is not firing because indicator input is not the actual thrust command input to engine unless the engine is on, and TTCA is at minimum position. Thrust command to engine, in AUTO mode, (GUID CONT switch is set to PGNS) is sum of thrust commands from LGC and TTCA. TTCA provides a minimum thrust command of 10% at all times; it cannot be set to zero. When THR CONT switch is set to AUTO position and TTCA is at minimum position, LGC commands 10% less than required and is summed with 10% command from TTCA to provide required thrust level. When THR CONT switch is set to MAN, LGC commands are removed and all thrust commands originate from TTCA.	Normally, during LGC command authority, both pointers will be aligned. If not, a malfunction exists or manual throttle authority is being introduced to enable smooth transition to full manual control. If manual control is desired, THR CONT switch is set to MAN when CMD pointer reaches 10%; pointers will then realign. If TTCA control is moved beyond minimum thrust position, LGC commands correspondingly less thrust. It is, therefore, possible in AUTO mode to command more thrust than LGC requires, but not possible to command less.

TABLE 8.3-II.
DISPLAYS AND CONTROLS ASSOCIATED
WITH THE LUNAR LANDING MANEUVER
(SHEET 6 OF 6)

Display/Control	Function	Remarks
Thrust/Translation Controller Assembly (TTCA)	The thrust/translation controller is, functionally, an integrated translation and thrust controller used to command vehicle translations by reaction control jet firing, and to throttle the descent engine between 10% and 92.5% maximum thrust magnitude. It is a three-axis, tee-handle, left-hand controller. Vehicle translations correspond approximately to astronaut movement of the tee-handle. Leftward or rightward movement commands translation along LM Y-axis; inward or outward movement commands translation along LM Z-axis; upward or downward movement commands translation along LM X-axis.	
T/W Indicator	Displays instantaneous X-axis acceleration in lunar g units (1 lunar g = 5.23 ft/sec^2).	Indicator, a self-contained accelerometer, may be used to provide a gross check of engine performance, because any given throttle setting provides specific acceleration when the vehicle has given mass.
X-Pointer Indicator	Displays forward and lateral velocities, lateral velocities only, or rendezvous radar LOS elevation and azimuth angular rates, depending upon setting of RATE/ERR MON switch and MODE SEL switch.	Forward and lateral velocities are coincident with LM Z and Y body axis velocities when PGNS drives display. When LR drives display, forward and lateral velocities are coincident with LM Z and Y axes (from hi-gate point to touch-down). When AGS drives display, lateral Y-axis velocity only is displayed. When RR is selected, LOS rates are displayed.
Display & Keyboard (DSKY)	See Table 8.3-III.	

TABLE 8.3-III.

LUNAR DESCENT DSKY PROCEDURES (SHEET 1 OF 4)

No.	Entry Point	Display	PROG	Purpose	Registers	LGC Operation	Crew Action	Remarks
1	Pre-ignition (VERB 37 ENTR 63 ENTR)	FL V06 N61	P63	Display time from ignition to high gate (TG), time from DPS ignition (TFI), and out-of-plane distance between LM orbital plane and current landing site (CR).	R1-xxBxx min, sec; TG R2±xxBxx min, sec; TFI R3±xxxx.x n.mi. CR "+" means landing site is north of LM orbital plane	When astronaut keys VERB 37 ENTR 63 ENTR, start P63 ignition algorithm.	PRO to 2 to approve display.	Alarm 01412 occurs if ignition algorithm does not converge; key VERB 37 ENTR 00 ENTR to stop calculations. Load NOUN 69 if required.
2		FL V50 N18	P63	Request maneuver to displayed angles (required ignition attitude).	R1 xxx.xx deg roll R2 xxx.xx deg pitch R3 xxx.xx deg yaw	Upon crew's PRO, maneuver to desired attitude.	Auto maneuver—PGNS AUTO, PRO to 2. Manual maneuver—PGNS ATT. HOLD, use ACA, PRO to 2. Bypass maneuver—ENTR to 3.	Display will flash at end of auto maneuver; key ENTR.
3		FL V50 N25	P63	Request LR antenna to descent position.	R1 00500	Test LR antenna position.	LDG ANT to DES, wait 10 sec, LDG ANT to AUTO, PRO to 4.	Display occurs only if LR antenna not in correct position.
4		FL V50 N25	P63	Request select PGNS control modes.	R1 00203	Test PGNS control modes. Perform MIDTOAVE routine.	GUID CONT-PGNS MODE CONT-AUTO THR CONT-AUTO PRO to 5.	Display occurs only if correct PGNS control modes not selected. Alarm 01703 occurs if MIDTOAVE calculations cause TIG to be slipped.
5		V06 N62	P63	Nonflashing display of magnitude of LM velocity (VI), TFI, and measured delta V (ΔVm).	R1 xxxx.x ft/sec VI R2 xxBxx min, sec TFI R3 xxxx.x ft/sec ΔVm	Countdown to ignition. Start AVERAGE-G at TIG-30 sec.	Set TTCA to minimum thrust. Arm DPS.	DSKY blanks from TIG-35 sec to TIG-30 sec.
6		FL V99 N62	P63	At TIG-5sec, request engine-on enable.	R1 xxxx.x ft/sec VI R2 xxBxx min, sec TFI R3 xxxx.x ft/sec ΔVm	Upon crew's PRO or at TIG, whichever comes later, turn on DPS.	PRO to 7 to enable DPS ignition.	LGC does not respond to ENTR. Verify +X ullage; if no ullage, key VERB 34 ENTR to terminate P63.

TABLE 8.3-III.

LUNAR DESCENT DSKY PROCEDURES (SHEET 2 OF 4)

No.	Entry Point	Display	PROG	Purpose	Registers	LGC Operation	Crew Action	Remarks
		V06 N62	P63	Nonflashing display of magnitude of LM velocity (VI), TFI, and measured delta V (ΔVm)	R1 xxxx.x ft/sec VI R2 xxBxx min, sec TFI R3 xxxx.x ft/sec ΔVm	Countdown to ignition.		Display continues until DPS ignition. Go to 8.
8		FL V06 N63	P63	Display difference between PGNS- and LR-derived altitude (ΔH), rate of change of altitude (H-DOT), and LM altitude above lunar radius at landing site (H).	R1 xxxxx. ft ΔH R2 xxxx.x ft/sec H-DOT R3 xxxxx. ft H R2: negative polarity indicates descent	At TIG+26 sec, command maximum DPS thrust.	Monitor thrust meters for good throttle-up. Key VERB 57 ENTR to enable LR state updates; key VERB 58 ENTR to disable LR state updates. Display is non-flashing when LR updates enabled.	Display continues until high gate. Go to 9. VERB 16 NOUN 92 ENTR can be used to monitor LGC throttle commands. Alarm 00511 indicates neither or both LR antenna position discretes present. NOUN 63 can be called at any time during descent.
9	High gate	FL V06 N64	P64	Display as follows: R1-time remaining until end of redesignation capability (TR) and angle below +Z axis of line of sight to current landing site (LPD); R2-H-DOT; R3-H.	R1 xxBxx sec, deg; TR, LPD R2 xxxx.x ft/sec H-DOT R3 xxxxx. ft H	Compute LPD angle corresponding to landing site as currently targeted.	Monitor attitude change. Key PRO to enable redesignation.	Crew can redesignate until TR=00 sec. At low gate, go to 10.
10	(a) MODE CONTROL-ATT HOLD and actuate ROD switch or (b) low gate	FL V06 N60	P66	Display as follows: forward component of LM horizontal velocity (FORVEL); H-DOT; H.	R1 xxxx.x ft/sec FORVEL R2 xxxx.x ft/sec H-DOT R3 xxxxx. ft H	Null horizontal velocity if in AUTO and maintain constant rate-of-descent.	Use ROD switch to change rate of descent (AUTO throttle mode) or use manual throttle. Can use ACA to null horizontal velocity when in ATT HOLD. At touchdown, push ENG STOP, key PRO, and set ENG ARM switch to OFF.	Crew can call P66 or NOUN 60 at any time during descent, but cannot return from P66 to P63 or P64.
11	V37 ENTR 68 ENTR	FL V06 N43	P68	Display LGC-calculated landing site.	R1 xxx.xx deg Lat (+ North) R2 xxx.xx deg Long. (+ East) R3 xxxx.x n.mi. Alt.	Store landing-site coordinates.	To store landing site coordinates, key PRO. To turn off DAP, set MODE CONTROL to ATT HOLD.	Landing programs are terminated. NO DAP light is illuminated when P68 selects minimum impulse mode (in ATT HOLD).

TABLE 8.3-III.

LUNAR DESCENT DSKY PROCEDURES (SHEET 3 OF 4)

No.	Entry Point	Display	PROG	Purpose	Registers	LGC Operation	Crew Action	Remarks
		FL V97 NOUN XX		Request crew perform engine-fail procedures.		Request crew perform engine-fail procedures. Guidance cycle continues.	Continue normal operation–PRO to VERB 06 NOUN XX Terminate current program–VERB 34 ENTR	
	V16 N68 ENTR	V16 N68		Display stable-member Z-axis range to landing site, time to guidance target and absolute value of velocity.	R1 xxxx.x n.mi. R2 xxBxx min; sec R3 xxxx.x fps		Push KEY REL to restore display of program in progress.	
	V16 N92 ENTR	V16 N92		Display LGC desired throttle command (THRCMD), H-DOT, and H.	R1 xxxxx. % THRCMD R2 xxxx.x ft/sec H-DOT R3 xxxxx. ft H		Push KEY REL to restore display of program in progress.	THRUST CMD meter is inactive when in manual throttle.
	V2X N69 ENTR X=1 through 5, depending on components required.	V2X N69		Modify landing site coordinates to achieve accurate landing (downrange, crossrange, altitude).	R1 xxxxx. ft Δz R2 xxxxx. ft Δy R3 xxxxx. ft Δx		Load required change in landing-site coordinates. V21–load R1 V22–load R2 V23–load R3 V24–load R1 and R2 V25–load R1, R2 and R3	Maximum values are 20,000 ft. Repeat if P63 is reselected.
	V59 ENTR			Command LR antenna to position 2.		Command LR antenna to position 2.		

TABLE 8.3-III.
LUNAR DESCENT DSKY PROCEDURES (SHEET 4 OF 4)

No.	Entry Point	Display	PROG	Purpose	Registers	LGC Operation	Crew Action	Remarks
	V60 ENTR			Display PGNS attitude rates on FDAI error needles.		Display PGNS attitude rates on FDAI error needles.		
	V61 ENTR			Display difference between current and DAP-commanded CDU angles on FDAI error needles.		Display difference between current and DAP-commanded CDU angles on FDAI error needles.		
	V62 ENTR			Display total attitude error (desired minus present CDU angles) on FDAI error needles.		Display total attitude error (desired minus present CDU angles) on FDAI error needles.		This mode automatically selected at start of P63 pre-burn attitude maneuver.
	V68 ENTR			Omit terrain model computations.		Omit terrain-model computations.		

Key PRO to approve VERB 06 NOUN 61.

2. P63 calls the Attitude Maneuver Routine (R60) to maneuver the LM to the initial burn attitude. The DSKY flashes request to "Please perform automatic maneuver":

FL VERB 50 NOUN 18 (R60)

R1	xxx.xx	deg	Roll
R2	xxx.xx	deg	Pitch
R3	xxx.xx	deg	Yaw

(a) to perform auto maneuver—set GUID CONT to PGNS, set PGNS MODE CONTROL to AUTO, and key PRO. Computer then fires RCS jets to attain displayed attitude. If PGNS MODE is set out of AUTO, computer terminates the maneuver immediately. Following astronaut or LGC termination of maneuver, computer again flashes VERB 50 NOUN 18 with desired angles. Astronaut can now perform another auto maneuver (PRO to 2), manual maneuver, or exit the maneuver (ENTR to 3).

(b) to perform manual maneuver—set PGNS MODE CONTROL to ATT HOLD and maneuver by using ACA and FDAI. When desired attitude is reached, can key PRO to trim attitude and again see flashing VERB 50 NOUN 18.

(c) to exit the requested maneuver—key ENTR when DSKY flashes VERB 50 NOUN 18 after auto or manual maneuver. R60 returns control to P63 (step 3).

3. P63 tests whether or not the LR antenna is in position 1. If it is not, the DSKY requests "Please select LR antenna descent position 1":

FL VERB 50 NOUN 25 (P63)

R1	00500	Checklist
R2	Blank	
R3	Blank	

Set the LDG ANT switch momentarily to DES, then to AUTO, and key PRO. LGC then checks antenna position again. If astronaut keys ENTR after the above display or if the LR is already in position 1, the astronaut sees the next display.

4. LGC checks the status of the PGNS control modes, and the astronaut might see the request "Please select PGNS control modes":

FL VERB 50 NOUN 25 (P63)

R1	00203	Checklist
R2	Blank	
R3	Blank	

Set PGNS controls as follows:

GUID CONT—PGNS
MODE CONT—AUTO
THR CONT—AUTO.

PRO to 5 when switches have been set as required; if crew prefers not to select these modes, it can key ENTR.

NOTE. —Appearance of a VERB 50 NOUN 25 display in spite of crew verification of correct switch settings indicate a channel-bit failure. The recommended procedure is to communicate with ground for proper procedure to follow. If display appears because the auto-throttle discrete has failed, and if ground communication not feasible, the crew can key in R03 and load a value of one into the D position of R2 in the VERB 04 NOUN 46 display.

5. P63 calls the State Vector Integration (MIDTOAVE) Routine (R41). MIDTOAVE integrates the LM state vector ahead to 30 sec before the scheduled time of DPS ignition (TIG). At TIG-35 sec, the DSKY blanks for 5 sec.

NOTE. —If there is insufficient time to complete the integration before the scheduled TIG, the computer turns on the PROG light, stores alarm code 01703, and slips DPS ignition to provide enough time to allow integration to finish. When ignition is slipped, the LGC commands full throttle at the new TIG+26 sec.

At TIG-30 sec, the LGC calls the Descent State Vector Update Routine (paragraph 8.3.5.1) to update the LM state vector every 2 sec. The DSKY displays

VERB 06 NOUN 62 (P63)

R1	xxxx.x	fps VI
R2	xxBxx	min, sec TFI
R3	xxxx.x	fps ΔVm

where VI is magnitude of LM velocity, TFI is time from DPS ignition, and ΔVm is the IMU-measured change in velocity.

Set TTCA to minimum thrust and arm DPS.

6. At TIG-5 sec, the DSKY requests "Please perform engine-on enable":

   <u>FL VERB 99 NOUN 62 (P63)</u>

   R1, R2, and R3 maintain VI, TFI, and ΔVm, respectively.

   Key PRO to enable DPS ignition.

   To reject ignition and terminate P63, set ENG ARM to OFF and key VERB 34 ENTR.

7. Upon receiving a PRO to VERB 99, the DSKY returns

   <u>VERB 06 NOUN 62 (P63)</u>

   R1, R2, and R3 maintain VI, TFI, and ΔVm, respectively.

8. At TIG-0 sec, the LGC turns on the DPS at 10 percent throttle and the DSKY displays

   <u>FL VERB 06 NOUN 63 (P63)</u>

R1	xxxxx.	ft ΔH
R2	xxxx.x	fps H-dot
R3	xxxxx.	ft H

   where ΔH is the difference between PGNS- and LR-derived altitude; H-dot is the rate of change of altitude; and H is the altitude above lunar radius at the nominal landing site.

NOTE.—R1 contains +99999 until the LR provides valid data. If ΔH is within limits for 10 sec or more, key VERB 57 ENTR to enable LR state-vector updates. R1 must continue to decrease with altitude, and must be less than 1000 ft after high gate. To stop LR updates, key VERB 58 ENTR.

The LGC uses the lunar terrain model only after LR altitude data are reasonable. Since the LGC does not model the entire lunar surface, an off-nominal trajectory could carry the LM over an area where the terrain model is inaccurate. In this event, the astronaut can key VERB 68 ENTR to eliminate the terrain model. The model is probably invalid for crossrange trajectory dispersions greater than ±5000 ft and downrange dispersions greater than ±3000 ft at the start of the visibility phase. A manual takeover or redesignation back to the pre-selected nominal site restores the validity of the terrain model.

At computed TIG+26 sec, the LGC commands the DPS to full throttle, and the ENG THRUST and CMD THRUST should indicate about 92 percent.

NOTE.—VERB 16 NOUN 92 ENTR can be keyed to verify that the LGC is working properly after throttle-up:

R1	xxxxx.	% THRCMD
R2	xxxx.x	fps H-dot
R3	xxxxx.	ft H

where THRCMD is the LGC desired thrust command (can be greater than 100 percent). R1 should be changing with time.

The astronaut turns on the DPS manually if the engine does not ignite by TIG+5 sec; if manual start or automatic throttle-up fails, the astronaut exits P63.

If the DPS cannot respond to the LGC's throttle-down signal that comes about 2 min before high gate, the computer will, after approximately 40 sec, pitch the LM 180 deg to correct for excessive thrust. This situation might arise if the manual throttle were improperly set.

If required, the astronaut can use MSFN data to load the LGC with a correction to the landing-site vector to improve the accuracy of the LGC targeting. This is accomplished by keying VERB 2x NOUN 69 ENTR and loading the desired registers:

R1	xxxxx.	ft ΔZ
R2	xxxxx.	ft ΔY
R3	xxxxx.	ft ΔX

where ΔZ, ΔY, and ΔX are, respectively, the desired changes in the landing site downrange, crossrange, and altitude components. No component should be changed by more than 20,000 ft. If NOUN 69 is loaded before P63 is selected, the LGC uses the data in computing the ignition time; if it is loaded between the ignition algorithm and TIG+26 sec, the LGC uses the data at throttle-up. In the latter case, a small attitude transient might be observed at throttle-up. If NOUN 69 is loaded after throttle-up, the data are used immediately, and the astronaut might observe an attitude transient. Additional NOUN 69 inputs replace unincorporated previous inputs; otherwise, they add to previous inputs.

9. P64 begins at high gate. The DSKY display contains:

FL VERB 06 NOUN 64 (P64)

R1	xxBxx	sec, deg; TR, LPD
R2	xxxx.x	fps H-dot
R3	xxxxx.	ft H

where TR is the time remaining until the end of landing-site redesignation capability and LPD is the angle below the LM's +Z axis of the line-of-sight to the current landing site.

The landing area becomes visible shortly after high gate, and the commander can use the DSKY LPD angle (voiced to him by the LM pilot) to determine where the computer will land the vehicle. An error in the LGC state vector will show up as an off-nominal landing site, and if the astronaut wants to redesignate, he keys PRO to FL VERB 06 NOUN 64. In AUTO, the LGC now accepts ACA inputs as redesignation commands, as long as TR on the DSKY is greater than zero.

Positive and negative pitch deflections produce, respectively, a 1-deg decrease and increase of the LPD angle indicating the currently targeted landing site. Left and right roll deflections produce, respectively, a 1-deg change left or right from the previously designated landing site position. When the LGC receives a redesignation input, it changes the components of the intended

landing-site vector by an amount corresponding to the number and direction of ACA movements.

Figure 8.3-2 shows the redesignation procedures. The return to detent indicates the redesignation command; the ACA must not be allowed to snap back across detent, or the LGC might receive a cancelling command. Elevation clicks cause vehicle pitch motions, and azimuth clicks cause pitch, roll, and yaw motions. Azimuth redesignations change the site perpendicular to the reticle, not to the local vertical. Therefore, any vehicle roll, as from a previous azimuth redesignation, will give an elevation component to azimuth redesignations and an azimuth component to elevation redesignations. Figure 8.3-1 shows how the plane of azimuth redesignations is skewed from the horizontal by the roll angle.

It is advisable to correct any major difference between the indicated and desired landing sites as soon as possible because as the LM approaches the computed site, the intended site will move off the window at an exponentially increasing rate. Small differences can be ignored, but the commander must immediately make significant corrections when he sees that the LGC is grossly off target; otherwise, he might lose sight of the desired landing site.

Uprange and downrange redesignations can have a significant effect on the available hover time. If the landing site is redesignated downrange, the available hover time decreases; hover time increases with uprange redesignations. Crossrange redesignations decrease hover time less significantly.

10. The Visibility Phase program continues until P66 begins, either when

(a) the astronaut sets PGNS MODE to ATT HOLD and actuates the ROD switch, or

(b) the LM reaches low gate.

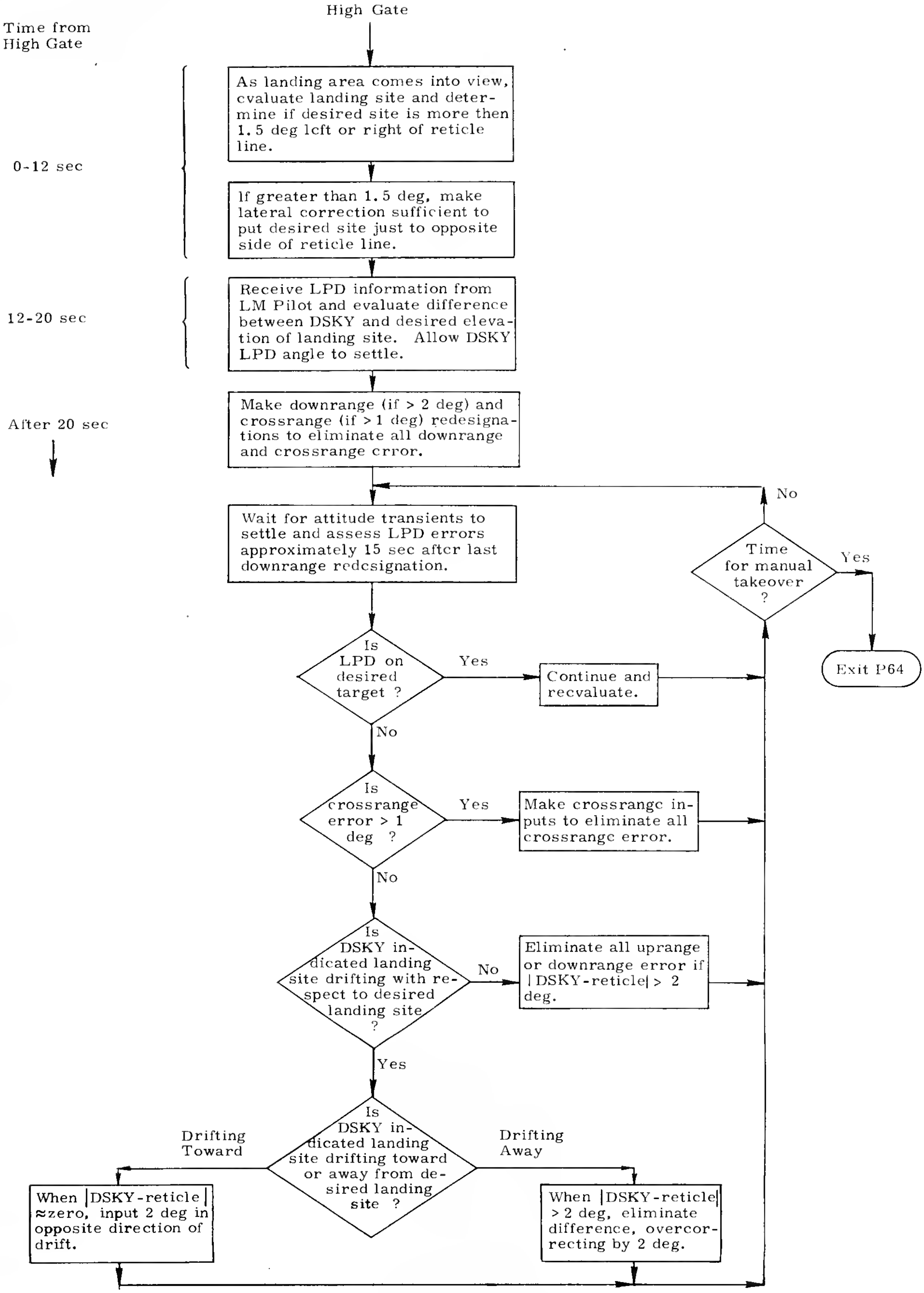

Figure 8.3-2. Landing-Site Redesignation Procedure

The DSKY display changes to

FL VERB 06 NOUN 60 (P66)

R1	xxxx.x	fps FORVEL
R2	xxxx.x	fps H-dot
R3	xxxxx.	ft H

where FORVEL is the forward component of the LM's horizontal velocity.

When not in manual throttle mode, use ROD switch to control rate of descent.

When LUNAR CONTACT—on, press ENGINE STOP and key PRO to stop RCS firings.

PGNS MODE—ATT HOLD

DES ENG CMD OVRD—OFF

ENG ARM—OFF

Guidance cycle continues to update state vector after touchdown, and astronaut can perform APS abort at any time before P66 exit.

11. Select P68.

VERB 37 ENTR 68 ENTR

P68 commands minimum-impulse DAP mode and displays current position vector as landing-site coordinates:

FL VERB 06 NOUN 43 (P68)

R1	xxx.xx	deg	Latitude (+North)
R2	xxx.xx	deg	Longitude (+East)
R3	xxxx.x	n.mi.	Altitude

NOTE.—NOUN 43 as first displayed will be in error by the amount of landing-site bias loaded in NOUN 69 plus any uncompensated LGC navigation error.

Load new data, if available.

Key PRO to store displayed coordinates.

P68 calculates LM attitude with respect to lunar surface and defines local-gravity vector to be parallel to landing-site radius vector, both for use by Lunar-Surface Alignment Program (P57).

P68 terminates automatically.

8.3.4 Program Alarms

This section describes the alarms that might be encountered during descent:

a. Alarm 00210 occurs if the IMU is not operating.

b. Alarm 00214 indicates the program was using the IMU when the IMU was turned off. Switch to manual attitude control or to AGS.

c. Alarm 00220 indicates IMU not aligned. Determine IMU orientation or set REFSMMAT flag.

d. Alarm 00401 occurs if the desired gimbal angles would yield gimbal lock.

e. Alarm 00402 indicates FINDCDUW is not controlling LM attitude because it has bad inputs. Switch to manual attitude control or to AGS.

f. Alarm 00511 indicates both or neither LR antenna position discrete(s) are present for more than 10 seconds (20 seconds at high gate). Switch LDG ANT to HOVER and contact MSFN.

g. Alarm 00520 indicates bad radar interrupt in R12. Key RSET and continue.

h. Alarm 00777 indicates PIPA fail. Consult ISS malfunction procedures or go to AGS if necessary.

i. Alarm 01107 indicates hardware—or software—restart failure. Switch to AGS or land manually.

j. Recurring alarms 31201, 31202, and 31203 indicate, respectively, that the computer has no available VAC areas, no available core sets, and too many tasks to perform. Continue program or reselect extended verb. If a restart occurs, the DSKY might blank briefly; the program continues.

k. Alarm 21406 indicates bad return from the time-to-target routine when used by the ignition algorithm. This could be caused by a bad uplink of state vector or landing site. Contact MSFN. Landing is No Go.

l. Recurring alarm 01406 indicates bad return from the time-to-target routine in P63 or P64. In AUTO, computer zeroes attitude rates. Go to P66 if possible.

m. Recurring alarm 01410 indicates overflow in guidance computations. In AUTO, computer zeroes attitude rates. Contact MSFN.

n. Alarm 01412 indicates ignition algorithm does not converge to solution. Key VERB 96 ENTR to stop integration and contact MSFN. Possibly caused by bad uplink of state vector or landing site.

o. Recurring alarm 01466 indicates too few throttlings are being performed in P66 because of high computer demand.

p. Alarm 01703 indicates MIDTOAVE calculations will finish too close to TIG to allow ignition on time. For large TIG slip, burn should not be performed; for small TIG slip, throttle up manually at TIG +26 sec DET time.

q. Flashing VERB 97 NOUN 63 indicates LGC-assumed engine failure at ignition. Key PRO to reset ΔV monitor to check again for engine-fail. ENTR causes ignition sequence to be repeated from TIG-5 sec. VERB 97 also flashes if engine fails during burn. PRO then continues normal operation; VERB 34 ENTR terminates current program; ENTR commands engine off and LGC flashes VERB 99. DPS restart undesirable in descent because guidance will resume at pre-high gate conditions.

8.3.5 Guidance Cycle

During the powered landing maneuver, the computer must periodically update the LM position and velocity and command the required amount and direction of thrust acceleration. These calculations are performed by a sequence of routines that repeats itself every 2 sec, called the guidance cycle (or Servicer).

The complete guidance cycle starts running at the time the DPS is commanded to full throttle in P63, and stops running when the astronaut calls P68 after touchdown. In the P63 and P64 guidance cycle, the LGC performs the following routines, in order, every 2 sec (refer to Figure 8.3-3 and -4):

a. The LGC reads the PIPAs every 2 sec.

b. The State Vector Update Routine computes the current LM position and velocity using IMU and LR data.

S—State Vector Update Routine
S'—Final Part of P66 SVUR
T—Throttle Routine
H—P66 Horizontal Guidance
G—Guidance-and-Control Routine
R—Auto Modes Monitor Routine
F—FINDCDUW
P—Time of PIPA Reading
V—P66 Throttle Calculations

NOTE: Consult mission documentation for precise values of event timeline.

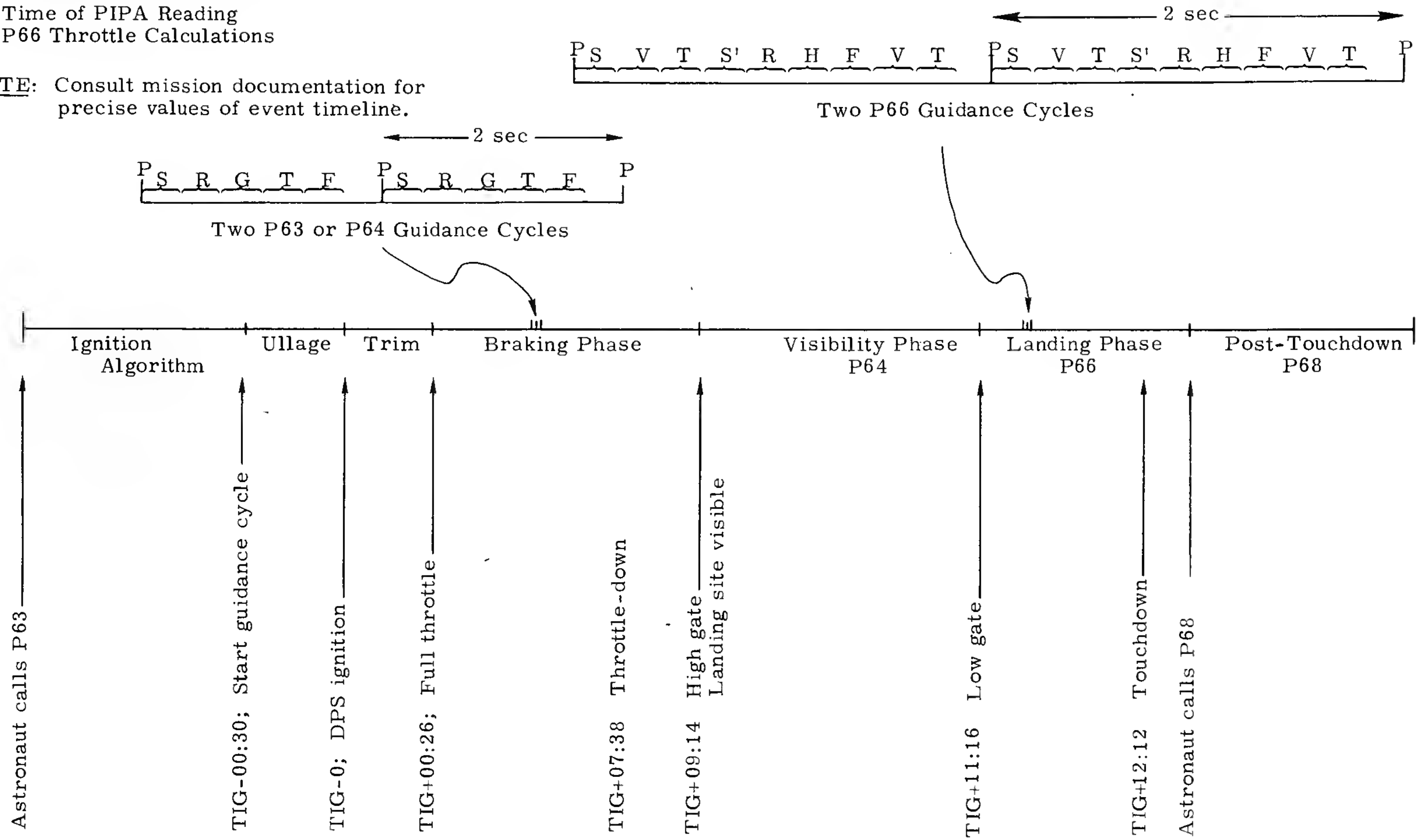

Figure 8.3-3. Timeline of Lunar Landing Guidance Cycle (not to scale)

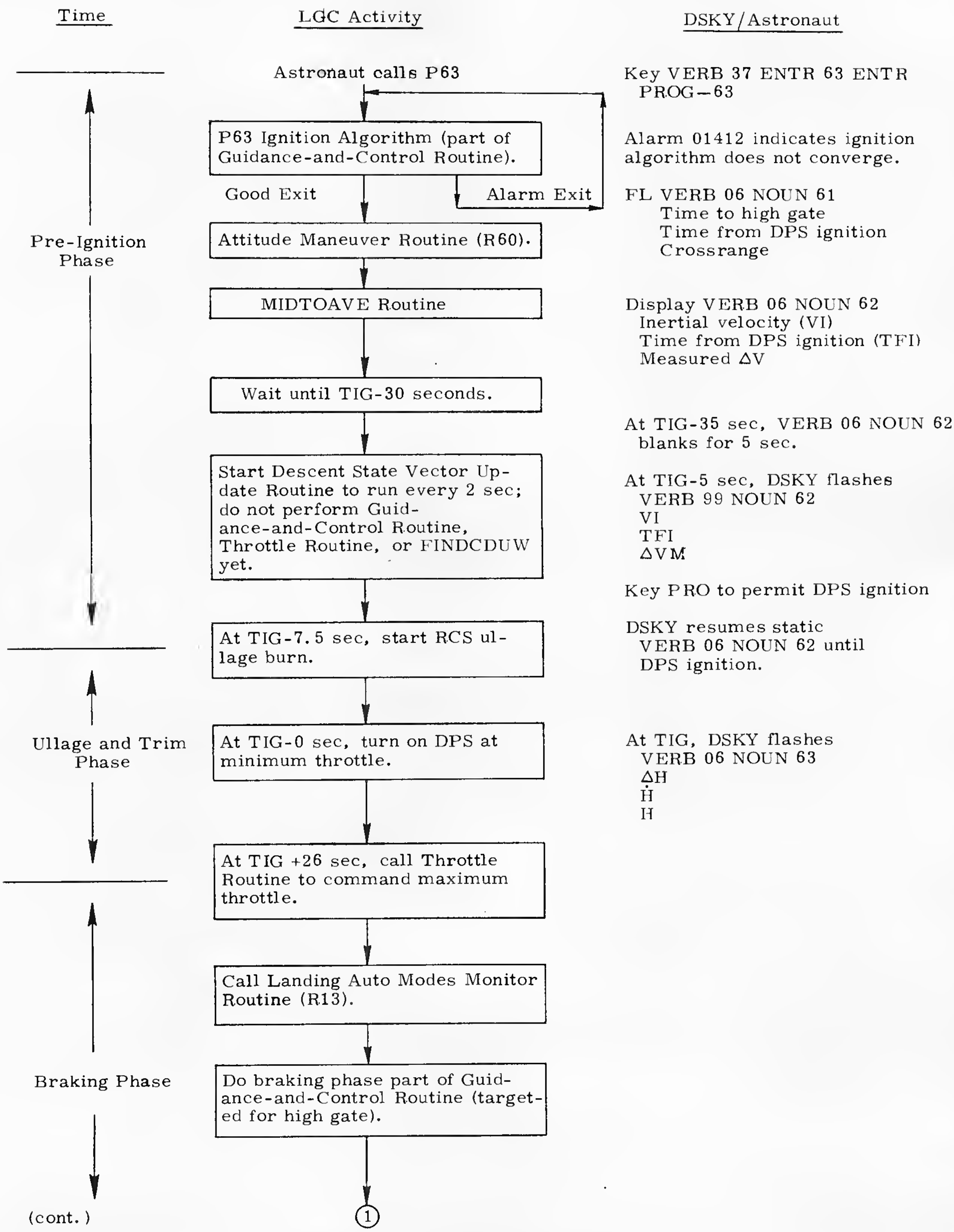

Figure 8.3-4. LGC Descent Computations (Sheet 1 of 3)

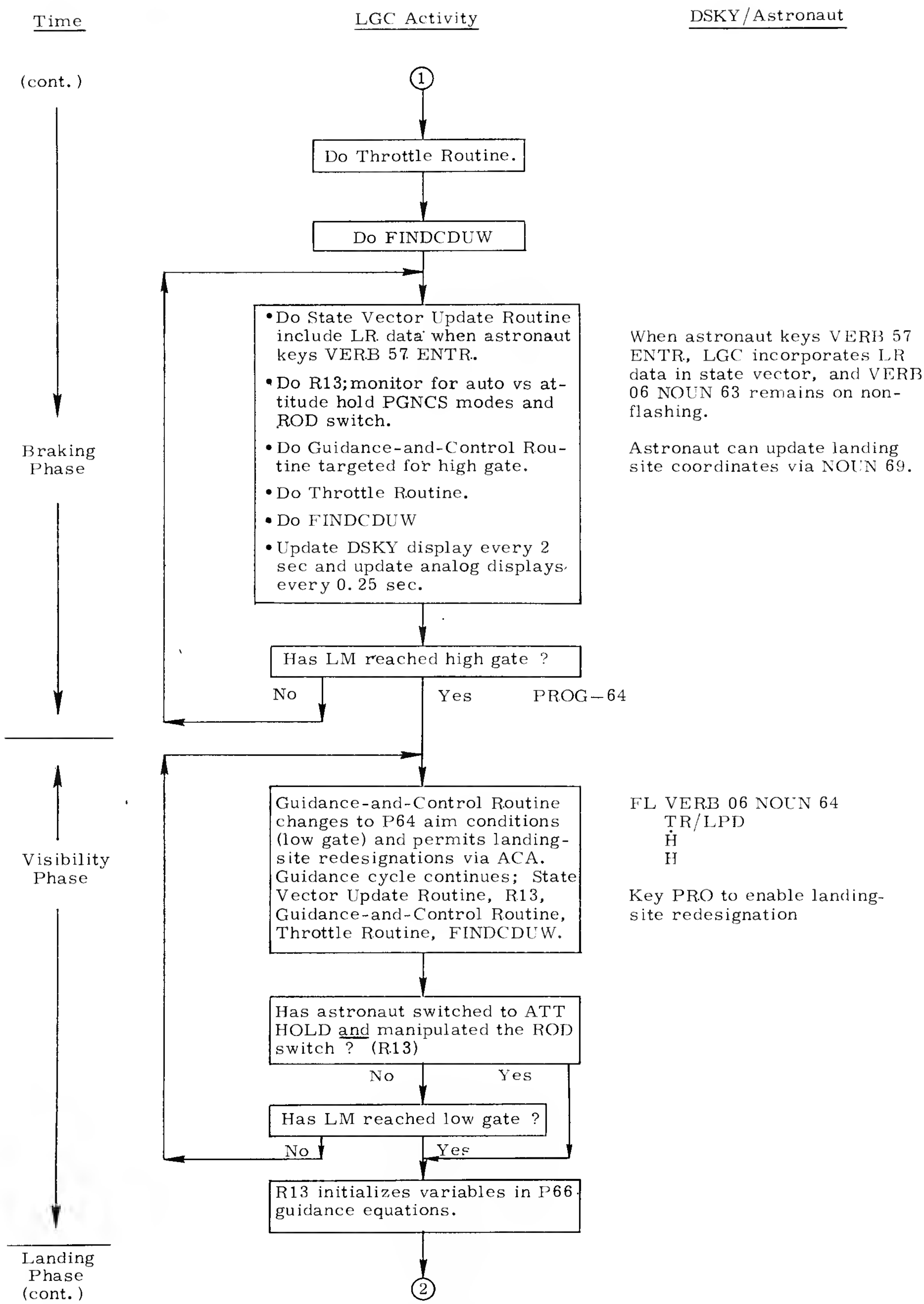

Figure 8.3-4. LGC Descent Computations (Sheet 2 of 3)

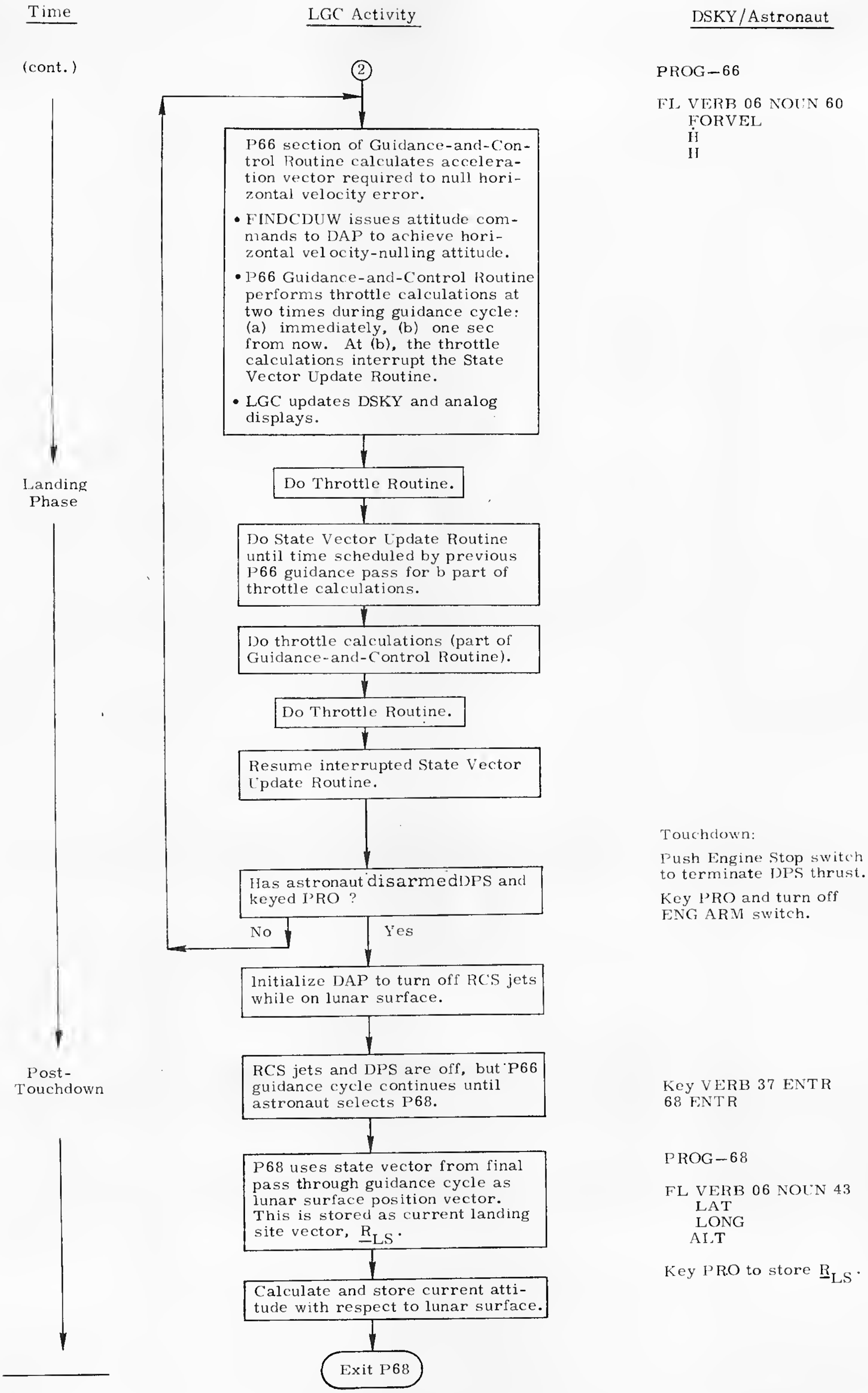

Figure 8.3-4. LGC Descent Computations (Sheet 3 of 3)

c. The Landing Auto Modes Monitor Routine (R13) monitors LGC inputs for conditions that require program change from P63 or P64 to P66.

d. The Guidance-and-Control Routine uses data from the State Vector Update Routine to calculate the LM attitude and DPS thrust required to reach the targeted conditions for each phase of the trajectory.

e. The Throttle-Command Routine computes the thrust increment required to achieve the thrust acceleration calculated by the Guidance-and-Control Routine, and issues the necessary command to the DPS.

f. The FINDCDUW routine receives thrust direction and window-pointing commands from the Guidance-and-Control Routine and provides the DAP with gimbal angle increments and rates needed for trajectory control.

g. DSKY displays are updated.

8.3.5.1 State Vector Update Routine

At the start of each pass through the guidance cycle, the current PIPA readings and the Average-g equations (paragraph 6.1.1) are used to update the state vector. The new state vector is stored in a temporary register and is modified later when LR data are converted into additional state-vector updates. Finally, the LR- and IMU-updated state vector is loaded into the permanent register that contains the current state vector.

During every pass through the State-Vector Update Routine (SVUR), certain conditions must be met before LR data are used to update the state vector. If any of the tests are failed, the state vector is updated using only IMU data, until the next pass through the SVUR. The tests are as follows:

a. The LM must not be in powered ascent or abort;

b. The LM altitude must be greater than 50 ft;

c. The astronaut must key VERB 57 ENTR to enable LR updates (VERB 58 ENTR inhibits LR updates);

d. The LR antenna must not indicate that it is in neither or both DESCENT and HOVER positions. If this test is failed for more than 10 sec (20 sec at high gate), the LGC turns on the PROG alarm light and stores alarm code 00511.

e. The LR antenna position must not have changed since the last R12.

In addition to the conditions listed above, the LR Data Read Routine, called during the SVUR, performs the following tests on the quality of LR data before the data are used in state vector computations:

a. The LGC must have received discretes from the LR indicating that the altitude and velocity beams have acquired the lunar surface and are returning signals that are strong enough to be useful. The ALT and VEL DSKY lights are illuminated continuously when the appropriate discrete is not received. The data must pass the test twice consecutively before the light is extinguished.

b. The most recent LR measurements must not differ from their previous values by more than a pre-specified amount. The LGC flashes the appropriate ALT or VEL DSKY light if the difference between successive readings has been too large twice in the past four cycles and is currently bad.

When these conditions are not met, the LGC does not use LR data to update the state vector. Instead, the IMU-derived state vector is stored as the current state vector, and control passes to the Guidance-and-Control Routine.

If the LR data are satisfactory, the SVUR uses them to compute the LM altitude above the local terrain. Because the IMU measurements are used to calculate the LM altitude above the landing site, the LR-derived altitude must be converted into altitude above the landing site before being used as a correction to the IMU-derived state vector. To accomplish this, the LGC uses a pre-stored terrain model of the lunar altitude variations along the planned landing trajectory. LR altitude data are incorporated as follows; (a) the LGC calculates the difference $\Delta H_{TEMPORARY}$ between the IMU altitude and the LR altitude; (b) the terrain model modifies $\Delta H_{TEMPORARY}$ to account for the difference between local and landing-site elevation and stores the result as ΔH; (c) the corrected altitude is computed as IMU altitude $+ \Delta H \times W$, where W is a pre-stored weighting function of magnitude < 1 that decreases linearly with increasing altitude. In P66, the LGC does not use the terrain model, because local terrain variations are then important to the crew. The astronaut can turn off the terrain model at any time by keying VERB 68 ENTR.*

The SVUR next uses LR data to update the LM velocity. Only one of the three LR velocity components is read each cycle, so that any given component is updated once every 6 sec. The LR-derived velocity update is then multiplied by a variable weighting factor before being incorporated into the IMU-derived state vector. Finally, the SVUR transfers H, H-dot, and the new state vector to the permanent LGC registers where they are accessible to the DSKY and analog displays and can be used by other routines in the guidance cycle.

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*To use the terrain model again, the astronaut must key VERB 25 NOUN 07 ENTR 75 ENTR 2000 ENTR ENTR.

8.3.5.2 Landing Auto Modes Monitor Routine

The Landing Auto Modes Monitor Routine (R13) follows the SVUR and monitors the output of the PGNS MODE CONTROL switch and the ROD switch. If the LM has reached low gate, or if the astronaut has set the MODE CONTROL switch to ATT HOLD and actuated the ROD switch, then R13 starts the P66 section of the Guidance-and-Control Routine. (Once this happens, it is impossible to get back into P63 or P64.) If these conditions are not met, R13 continues the P63 or P64 section of the Guidance-and-Control Routine.

8.3.5.3 Guidance-and-Control Routine (P63 and P64)

The Guidance-and-Control Routine first updates the inertial coordinates of the current landing site to account for lunar rotation since the last pass through the guidance cycle, and also incorporates any landing site changes that the astronaut might have loaded via NOUN 69. During the visibility phase, the routine then includes any redesignations commanded by the astronaut using the ACA, and computes the LPD angle corresponding to the redesignated landing site and the time remaining for redesignations.

The LGC next computes the vector representing the acceleration (including gravity and DPS thrust) that must be applied to the LM in order to reach the target. The required acceleration is a function of the time to reach the target point of the current trajectory phase, the current state vector, and the position, velocity, and acceleration of the target conditions. The calculated thrust acceleration vector that the DPS must supply is then the difference between the total required acceleration vector and the lunar gravitational acceleration vector. Finally, the LGC calculates the yaw attitude required to point the LPD at the landing site and calls the Throttle-Command routine and the FINDCDUW routine.

8.3.5.4 Throttle-Command Routine

The Throttle-Command Routine calculates a thrust increment command that is the difference between the thrust required to satisfy guidance commands and the thrust as currently measured. This command is sent from the LGC to the Descent Engine Control Assembly. The LGC operates the DPS at either maximum thrust or in the region between 10 percent and 65 percent thrust. The DPS also receives throttle commands from the manual throttle control on the TTCA, and will always deliver thrust proportional to the sum of the manual and LGC throttle signals.

8.3.5.5 FINDCDUW

The FINDCDUW routine is the interface between the Guidance-and-Control Routine and the DAP, and performs the following: (a) computes the gimbal angle increments and attitude rates needed to align the thrust vector with the required acceleration vector; (b) aligns the +Z half of the LM X-Z plane with the vector that points the LPD at the landing site; (c) issues alarm code 00401 if required to attain a middle gimbal angle of 70 degrees or more (gimbal lock); and (d) issues alarm code 00402 if Guidance-and-Control Routine supplies inadequate pointing commands. FINDCDUW commands zero attitude rates if alarm conditions c or d exist.

8.3.5.6 P66 Guidance Cycle

During P66, throttle commands are calculated and sent twice per guidance cycle; attitude control commands are sent once per guidance cycle. Upon entry from R13, the P66 Guidance-and-Control Routine first calculates the thrust acceleration vector required to null the LM horizontal velocity and calls FINDCDUW to orient the thrust vector accordingly. The Guidance-and-Control Routine next computes the magnitude of the thrust vector required to maintain the desired rate of descent and calls the Throttle-Command Routine. One sec later, interrupting the next State Vector Update Routine, the LGC again performs thrust magnitude calculations and the Throttle-Command Routine.

8.3.5.7 Miscellaneous Routines

The following routines run every 0.25 sec during the guidance cycle:

a. The R10/R11/R12 Service Routine (R09) updates the VEL and ALT DSKY lights.
b. The Abort Discretes Monitor Routine (R11) monitors the ABORT and ABORT STAGE pushbuttons and calls the DPS or APS Abort Program if aborts are permitted and the astronaut depresses the appropriate pushbutton. P63 permits aborts at any time after DPS ignition. If CHANBKUP bit 1 is set to 1 before PDI to protect against failure of ABORT or ABORT STAGE buttons, the LGC will not recognize inputs from these buttons. ABORT STAGE is still effective for hardware staging, however.
c. If the MODE SEL switch is set to PGNS, the Landing Analog Displays Routine (R10) updates the forward and lateral velocity crosspointers and the ALT and ALT RATE meters once every 0.25 sec.

The DPS/APS Thrust Fail Routine (R40, Figure 3.3.1-1) runs once every 2 sec and monitors the PIPA outputs for evidence of DPS thrust failure. If, during descent, the change in velocity fails to reach a predetermined level that is acceptable to the LGC, R40 keeps the current DSKY display, but flashes VERB 97 ("Please perform engine-fail procedures") and does not turn off the DPS. There are three available responses to this display:

a. PRO.—The LGC reinitializes the thrust monitor to again determine if there is sufficient thrust; the normal thrusting display returns.
b. ENTR.—The LGC commands DPS off and flashes VERB 99 NOUN 62 ("Please perform engine-on enable").*
c. VERB 34 ENTR.—The LGC terminates the descent programs and flashes VERB 37. (Refer also to paragraph 3.3.1.4.1.)

8.3.6 TLOSS

If the LGC computation demand is extremely severe, it is remotely possible that the computer will not be able to complete all required guidance cycle calculations within the two-second-interval between PIPA readings. For example, on APOLLO 11, the rendezvous radar introduced counter activity that caused a demand on the computer duty cycle of approximately 15 percent (15 percent TLOSS). Excessive DSKY action can also cause TLOSS. Program and procedural changes have now made TLOSS in excess of 4 percent extremely unlikely. The ground can detect the presence of TLOSS via telemetry and will inform the astronaut of any TLOSS problems.

During the visibility phase, a TLOSS greater than 12 percent will cause a routine in the guidance cycle to fail to finish before the next guidance cycle is scheduled. Since FINDCDUW is the last routine in the cycle, it will most probably be interrupted and its attitude commands suspended until the TLOSS demand drops to the point where the interrupted routine can be completed. If TLOSS continues, another FINDCDUW might be interrupted and its attitude commands suspended also. If enough jobs are suspended (14 percent TLOSS), all but the most recent will be eliminated by a software restart, and the LGC will issue alarm codes 31201 or 31202. If there are not enough suspended jobs to cause a restart, the suspended jobs will await free computer time during which they will issue their now-invalid attitude commands. Thus, near the end of P64, the LM could pitch back to the attitude

*A DPS restart in descent is undesirable because DPS throttle-up and throttle-down would be delayed, and the descent trajectory would be degraded.

desired near the beginning of P64. The computer will return the LM to the proper attitude when the suspended jobs are exhausted. If TLOSS is present in P64 and the LPD indicates an acceptable landing site, the astronaut can ignore erroneous attitude commands by switching to ATT HOLD and using the FDAI needles. In AUTO mode with TLOSS, the astronaut must be prepared to override automatic guidance commands.

P66 has been programmed to tolerate moderate amounts of TLOSS. In P66, two situations could arise from TLOSS; (a) delayed P64 jobs will have the same effects in P66 as in P64; (b) if there are no leftover P64 jobs and TLOSS occurs, some P66 guidance, throttle, and DAP commands will be deleted. Omission of P66 guidance prolongs the previous throttle and attitude-rate commands two seconds longer than intended. This might result in attitude or altitude-rate overshoot when a P66 cycle is omitted concurrent with changes in attitude or altitude rate. For TLOSS greater than 12 percent, every second P66 guidance pass is omitted. In this case, throttle and attitude commands may gradually diverge; the LGC will display alarm 01466 and continue to omit P66 guidance, if necessary.

SECTION 9.0

ADDITIONAL EXTENDED VERB ROUTINES

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9.1 Introduction

This section provides a description of routines that are callable by the crew. Each of these routines is initiated by the selection of an Extended Verb.*

CMC routines are described in subsection 9.2; LGC routines in subsection 9.3. A general discussion of the Extended Verbs and their operational restrictions is given in Subsection 10.1.

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* Some routines initiated by Extended Verbs are described in other sections of this volume. For each Extended Verb, a reference to the associated routine is provided in Section 10.

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SUBSECTION 9.2

ADDITIONAL CMC EXTENDED VERB ROUTINES

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9.2.1 R03, Digital Autopilot (DAP) Data Load—CMC

R03 allows the crew to load and verify CMC DAP data and provides the crew with the means for selecting appropriate coast autopilots. The computer logic is so arranged that, after selecting R03 and entering or verifying data, a single extended verb will allow the appropriate DAP to become active.

The following types of information, needed by the autopilots, can be loaded via R03.

1) Mass of the vehicle
2) Pitch and yaw trim for the SPS engine [physically a function of the vehicle center of gravity (c.g.)]
3) Configuration of the vehicle (for example, SIVB, CSM alone)
4) Quad information (i.e., which quads are enabled, and which are to be used for roll and X-translation)
5) Deadband width, maneuver rate.

No one autopilot requires all types of information. Good knowledge of pitch and yaw trim is important during TVC maneuvers in order to point the thrust vector through the vehicle c.g. and thus to eliminate or minimize disturbance torques and start-up attitude transients. Accurate knowledge of vehicle inertias, which are computed within the CMC as a function of vehicle mass and configuration, minimizes fuel expenditure during RCS DAP operation.

Pitch trim, and yaw trim are updated by the TVC DAP during SPS maneuvers. RCS maneuvers and the coast autopilots, however, do not update such information. Further, when the vehicle changes configuration, there is no onboard program that automatically calculates the new mass, pitch trim, and yaw trim. Therefore, R03 must be used after a change in vehicle configuration, and is usually checked before each thrusting maneuver.

9.2.1.1 Computational Sequence

The computational sequence of R03 is shown in Figure 9.2.1-1. After VERB 48 ENTR is received from the DSKY, R03 checks to determine whether the TVC DAP, or any extended verb is active. If so, R03 illuminates the OPR ERR light and terminates. If not, VERB 04 NOUN 46 is flashed for astronaut approval or change. NOUN 46 contains the DAP data code. Every octal digit assumes individual importance, and is, therefore, treated separately as an alphameric letter in Table 9.2.1-I. Each octal digit (i.e., each letter in the table) pertains to a different aspect

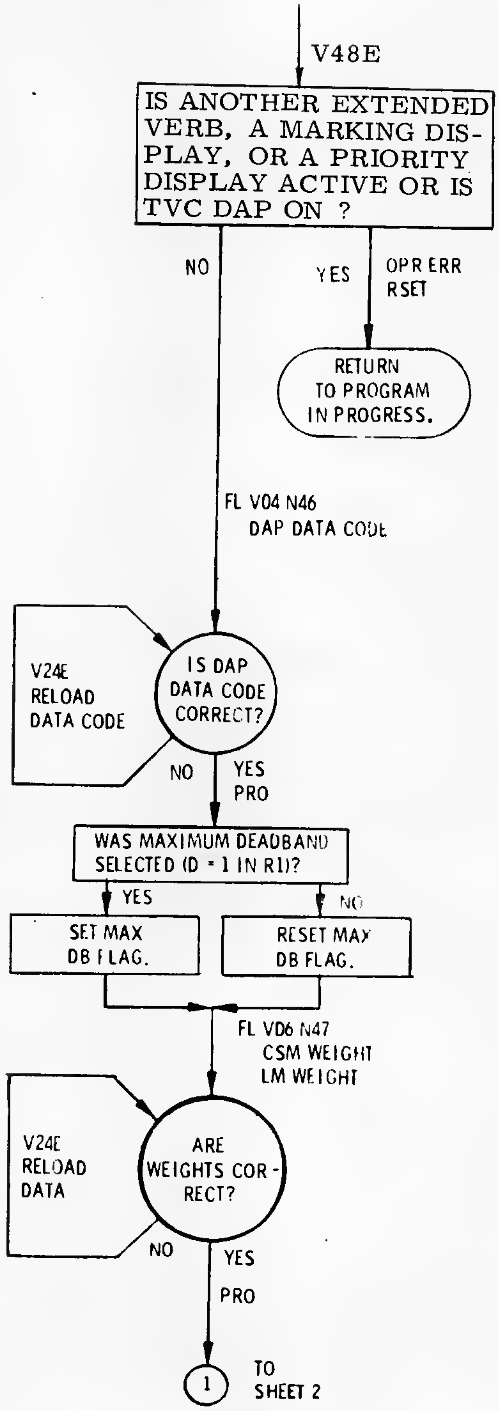

Figure 9.2.1-1. CMC Digital Autopilot (DAP) Data Load Routine (CSM R03)
(Sheet 1 of 2)

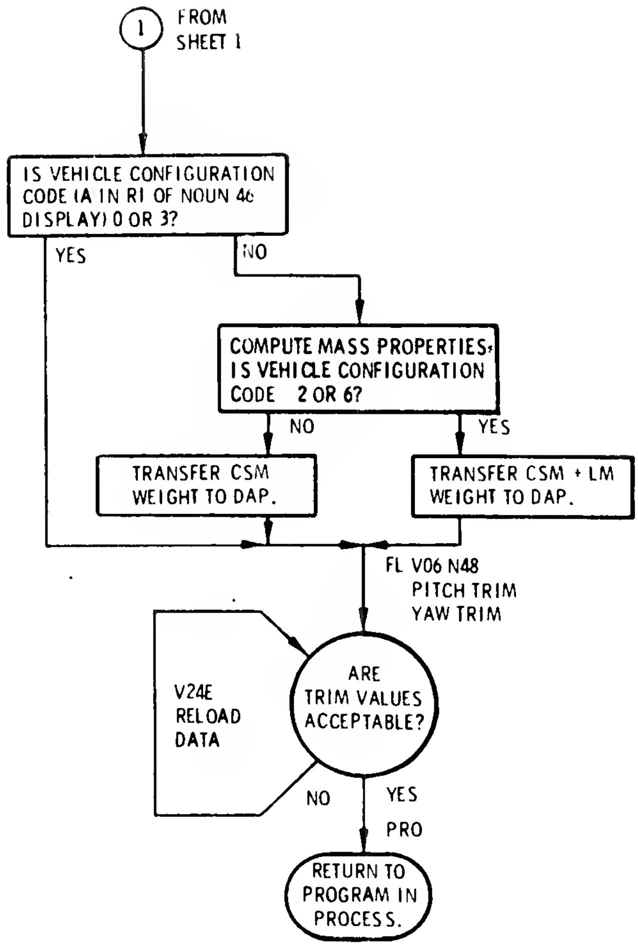

Figure 9.2.1-1. CMC Digital Autopilot (DAP)Data Load Routine (CSM R03)
(Sheet 2 of 2)

TABLE 9.2.1-I

DAP DATA-LOAD ROUTINE DISPLAYS (CSM R03)
(SHEET 1 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
FL V04 N46	R03	DAP configuration data	R1 of VERB 04 NOUN 46 must be loaded with the correct code, as follows: A Vehicle configuration code 0 = no DAP 1 = CSM 2 = CSM+LM (ascent+descent) 3 = SIVB 6 = CSM+LM (ascent only) B Quad AC for +X translation code 0 = do not use quad 1 = use quad C Quad BD for +X translation code 0 = do not use quad 1 = use quad D Deadband code 0-0.5 deg 1-5.0 deg E Maneuver rate code 0-0.05 deg/sec 1-0.2 deg/sec 2-0.5 deg/sec 3-2.0 deg/sec NOTE: If both B and C display zero, 4-jet translation will be used.	R1 xxxxx* octal
FL V04 N46	R03	Data code	R2 of VERB 04 NOUN 46 must be loaded with the correct code, as follows: A Quad AC or BD roll code 0 = use BD 1 = use AC B Quad A Code 0 = do not use quad 1 = use quad C Quad B Code 0 = do not use quad 1 = use quad	R2 xxxxx* octal

*The most significant digit (i.e., leftmost digit) refers to A; the next most significant digit refers to B, and so on.

TABLE 9.2.1-I

DAP DATA-LOAD ROUTINE DISPLAYS (CSM R03)
(SHEET 2 OF 2)

DSKY	Initiated by	Purpose	Condition	Register
			D Quad C code 0 = do not use quad 1 = use quad E Quad D code 0 = do not use quad 1 = use quad	
FL V06 N47	R03	CSM weight		R1 xxxxx lbs
FL V06 N47	R03	LM weight		R2 xxxxx lbs
FL V06 N48	R03	Pitch engine trim gimbal angle		R1 xxx. xx deg
FL V06 N48	R03	Yaw engine trim gimbal angle		R2 xxx. xx deg

of the DAP. A flashing VERB 06 NOUN 47 follows, showing the CSM and LM weights for approval or change. Usually, the ground voices up such information. After PRO is received to the NOUN 47 display, NOUN 48 is flashed, displaying the SPS engine trim gimbal angles (physically a function of c.g.) for approval or change. A PRO response to the NOUN 48 display terminates R03.

Changes from one RCS DAP to another are made automatically, at termination of R03. But a transition from one of the following configurations (1) Saturn DAP, (2) RCS DAP, (3) no DAP to another requires execution of VERB 46 ENTR.

9.2.1.2 Program Alarms

The OPR ERR light is illuminated if the TVC DAP is on, any extended verb is operating, or if there is a priority display on the DSKY when R03 is keyed in.

9.2.1.3 Restrictions and Limitations

PRO responses to the VERB 04 NOUN 46 and the VERB 06 NOUN 47 displays are necessary if the loaded data is to be converted into CMC parameters used by the autopilots. Keying a VERB 34 ENTR will not cause the required conversion.

Quads A and C cannot be failed (inhibited) simultaneously. Also quads B and D cannot be failed simultaneously.

9.2.1.4 Restarts

R03 is not restart protected. Should a restart occur, the astronaut must reselect R03.

9.2.2 R05, S-Band Antenna Routine—CMC

This paragraph will be supplied for Revision 4 at a later date.

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9.2.3 R30, Orbital-parameters Display—CMC

VERB 82 ENTR initiates R30, which computes orbital parameters. The parameters computed by R30 can be used to monitor the progress of thrusting maneuvers, or to check the current orbit during coasting flight.

9.2.3.1 Inputs

R30 inputs are delineated in Table 9.2.3-I.

If AVERAGEG is running—i.e., during powered flight—there are no astronaut inputs to R30. The routine simply uses the current state vector, as updated by AVERAGEG, to calculate the displayed parameters. If AVERAGEG is not running—i.e., during coasting flight—there are two astronaut inputs to R30:

1. Choice of vehicle—LM or CM
2. Time for which the orbital parameters are to be calculated.

Input 2 is necessary because R30 calculates orbital parameters using calculations that do not take perturbation effects into account. These calculations are discussed in more detail in paragraph 9.2.3.6.

9.2.3.2 Outputs

R30 outputs are delineated in Table 9.2.3-II.

The following parameters are always computed:

1. Apogee altitude
2. Perigee altitude
3. Time of free fall to the orbital interface* (TFF), or
4. Time from perigee, TPER, if the current orbit does not intersect the orbital interface.

In addition, if the current major mode is P11 (Earth-orbit-insertion Monitor Program) or P00 (CMC Idling Program), R30 also computes the miss distance,

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*The orbital interface is 35,000 feet above the current landing site radius in lunar orbit, and 300,000 feet above launch pad radius in earth orbit.

TABLE 9.2.3-I

ORBITAL-PARAMETERS DISPLAY ROUTINE
(CSM R30) INPUTS*

DSKY	Initiated By	Purpose	Condition	Register
FL V04 N12	R30	Assumed vehicle code. Initially displays 00001, indicating CM. VERB 22 ENTR 2 ENTR indicates LM is to be assumed vehicle.	Request astronaut to indicate assumed vehicle	R1 00002 R2 oooox
FL V06 N16	R30	Initially displayed as all zeros, indicating current time. If other than current time, is desired, it should be loaded via VERB 25 ENTR, in ground elapsed time (GET).	Time at which the calculations are to be valid	R1 ooxxx. hrs R2 oooxx. min R3 oxx.xx sec

*No astronaut inputs are required when AVERAGEG is running.

TABLE 9.2.3-II

ORBITAL-PARAMETERS DISPLAY ROUTINE
(CSM R30) OUTPUTS

DSKY	Initiated By	Purpose	Condition	Register
FL V16 N44	R30	These apsidal altitudes measured above launch pad radius, when in the earth's sphere, and above the latest landing site, when in the moon's sphere.	Apogee altitude Perigee altitude	R1 xxxx.x n.mi. R2 xxxx.x n.mi. Maximum number (9999.9) if scaling is exceeded.
		Once computed, counts down. Sign convention is in text.	Time to interface altitude (free fall)	R3 xxBxx min, sec
NOUN 32 ENTR (keyed after FL VERB 16 indicates R30 calculations are completed).	Astronaut	Computed when current orbit does not intersect the interface altitude, and then counts down. Set to zero otherwise.	Time to perigee (free fall)	R1 ooxxx. hrs R2 oooxx. min R3 oxx.xx sec
NOUN 50 ENTR (keyed after FL VERB 16 indicates R30 calculations are completed).	Astronaut	Computed during P11 and P00	Splash error Perigee altitude Time to interface (free fall)	R1 xxxx.x n.mi. R2 xxxx.x n.mi. R3 xxBxx min, sec

SPLERROR, between the splashpoint currently stored in the CM computer and the expected splashpoint arising from the current trajectory.

9.2.3.3 Options

The options discussed in this paragraph are as follows:

1. Choice of vehicle
2. Choice of NOUN to monitor

If AVERAGEG is running, the astronaut has no choice of vehicle; the CM is always the vehicle for which the parameters are calculated. Otherwise, the choice of vehicle clearly depends on which vehicle's orbital parameters the astronaut needs.

The astronaut can monitor three nouns, NOUN 44, NOUN 32, and NOUN 50. In most cases, NOUN 44, which R30 flashes automatically, gives all the information computed by R30; it contains apogee altitude, perigee altitude, and time of free fall to the interface altitude. An exception is when the current orbit does not intersect the interface altitude. Then R30 calculates the time of free fall to perigee in hr, min, and sec; this display can be called in NOUN 32.

If P00 or P11 is running, NOUN 50 is the desired display, since NOUN 50 shows the splash error, as well as perigee altitude and time of free fall to the interface altitude. If the apogee is above 300,000 feet, and the perigee is below 300,000 feet, the splash error is displayed as the distance between the predicted and the desired abort target. If either of these conditions is not satisfied, as in the early stages of boost, or when the CM is already in orbit, the splash error is displayed as the distance between the present position vector and the desired abort target.

9.2.3.4 Computational Sequence

Figure 9.2.3-1 illustrates the computational sequence of R30. After the astronaut selects R30, via VERB 82 ENTR, R30 determines whether another extended verb or priority display is active. If so, R30 illuminates the OPR ERR light and terminates. If the astronaut still desires R30, he must terminate the other extended verb and reselect R30.

If no other extended verb or priority display is operating, R30 next determines whether AVERAGEG is running. If so, R30 calculations are updated about every 2 seconds. If not, the calculations are done once, with the exception that the displayed times are made to count down.

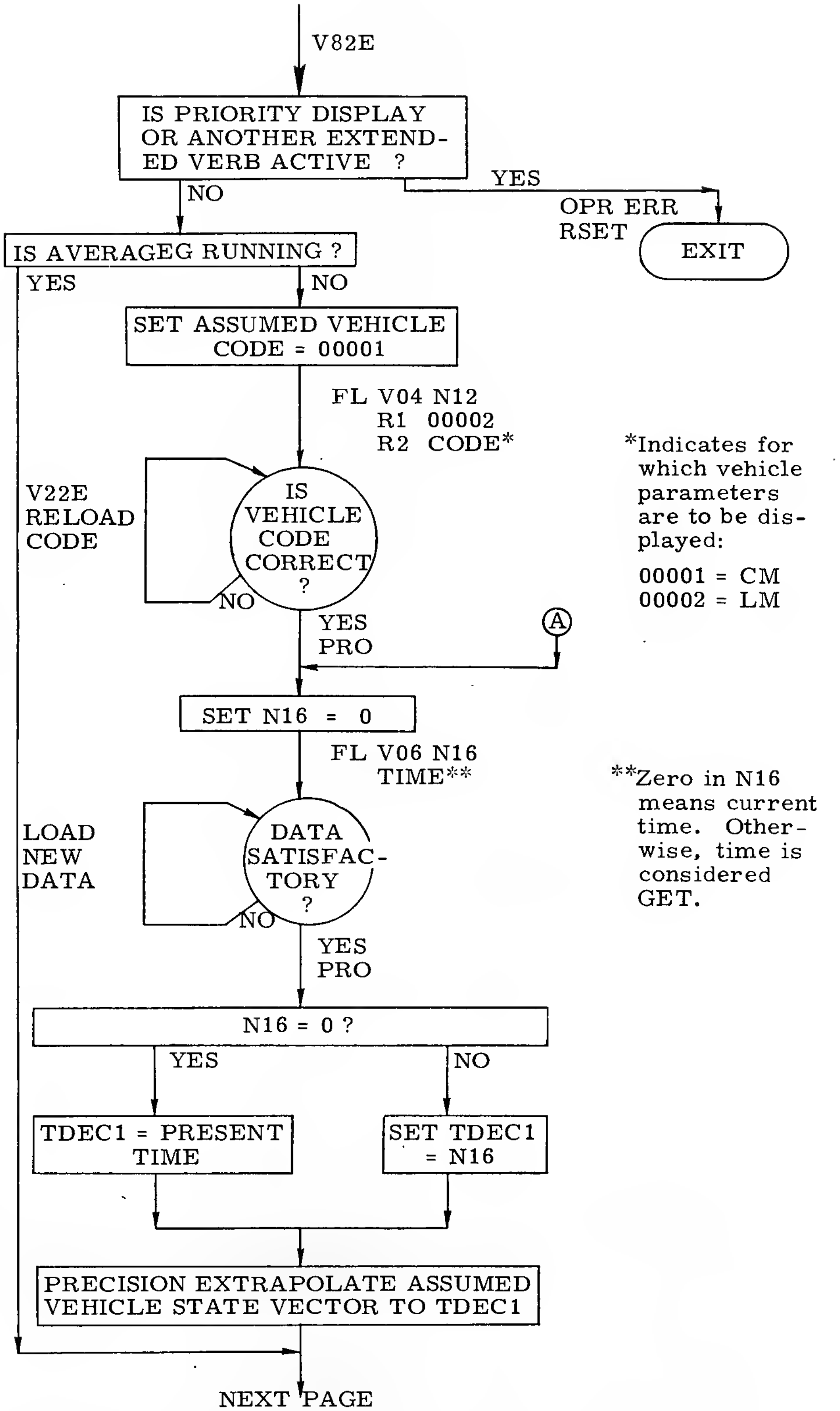

Figure 9.2.3-1. Orbital-parameters Display Routine (CSM R30) (Sheet 1 of 2)

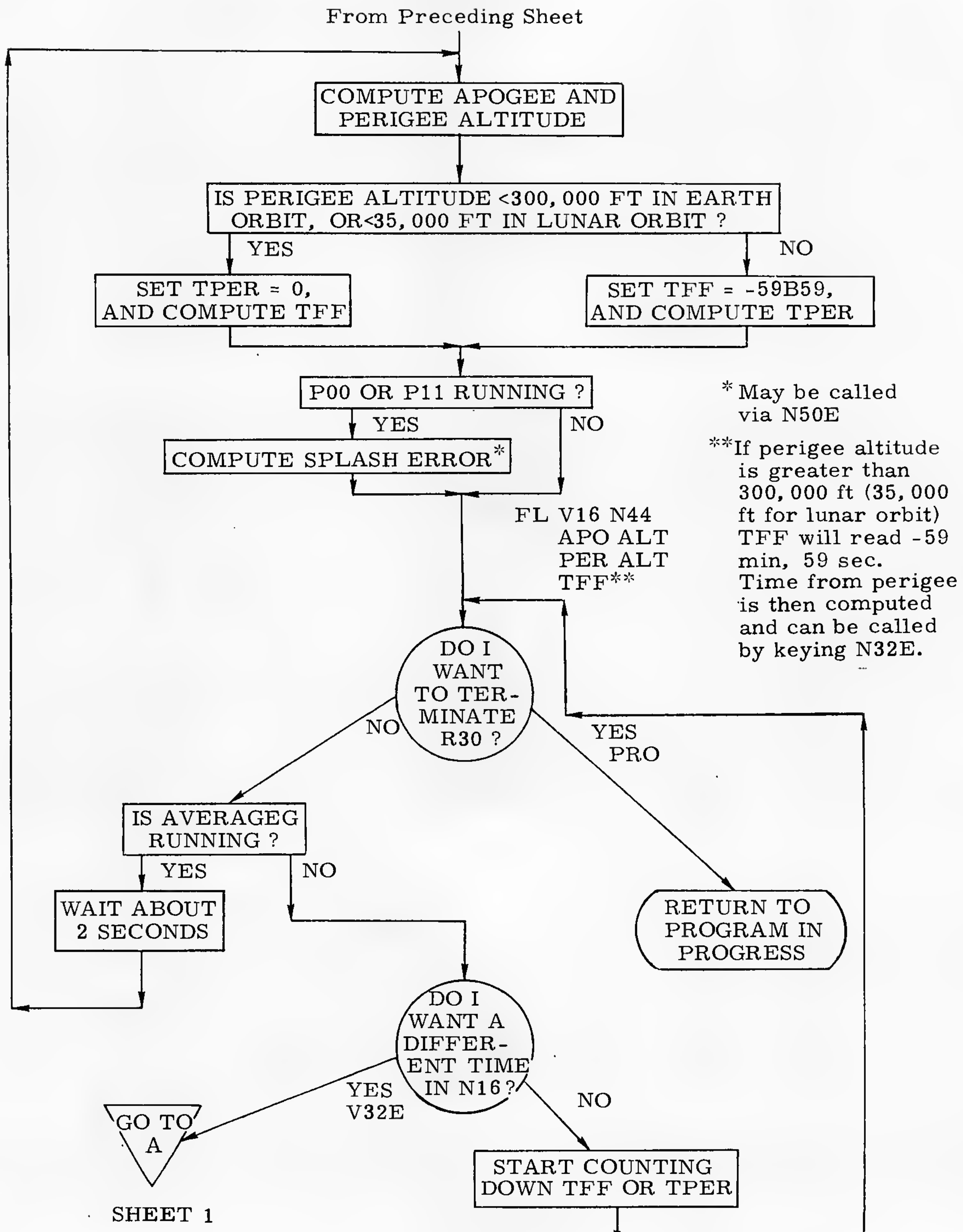

Figure 9.2.3-1. Orbital-parameters Display Routine (CSM R30) (Sheet 2 of 2)

9.2.3.4.1 R30 AVERAGEG Calculations.—During AVERAGEG operation, R30 begins calculation of the outputs listed in paragraph 9.2.3.2 as soon as the CM computer can schedule them—that is, as soon as AVERAGEG is completed for the current cycle. R30 uses the current state vector, and its associated time, updates its calculations approximately every two seconds, depending on the availability of computer time and flashes the results in a VERB 16 NOUN 44 display. If P11 is running, the astronaut should key in NOUN 50 ENTR to monitor the splash error. R30 automatically terminates when AVERAGEG terminates (i.e., at selection of a new program). If the astronaut wishes to terminate R30 before AVERAGEG terminates, he can respond to the flashing VERB 16 NOUN 44 or NOUN 50 with a PRO.

9.2.3.4.2 R30 Coasting Flight Calculations.—If AVERAGEG is not running, R30 must have two inputs from the astronaut (1) the assumed vehicle, and (2) the time at which the calculations are to be valid. Accordingly, R30 flashes VERB 04 NOUN 12, requesting choice of vehicle, and follows a PRO response to that display with a flashing VERB 06 NOUN 16, requesting the desired time. After a PRO response to the second display, R30 uses Coasting Integration to obtain the orbit at the time indicated by NOUN 16, and begins calculations of the orbital parameters. If the current orbit intersects the interface altitude, R30 calculates TFF, sets TPER to zero, and begins counting down. If the current orbit does not intersect the interface altitude, R30 sets TFF to -59B59, calculates TPER, and begins counting down.

Since R30's calculations are conic, based on the orbit extrapolated to the time indicated by NOUN 16, different results will be obtained from different NOUN 16 times. If a different time is desired, the astronaut can key VERB 32 ENTR in response to flashing VERB 16 NOUN 44, after which R30 flashes VERB 06 NOUN 16, requesting a new time. A PRO response to flashing VERB 16 NOUN 44 terminates R30.

9.2.3.4.3 Sign Conventions.—The sign convention for TFF and TPER is as follows: the DSKY display is negative and decreasing (in magnitude) as the interface altitude approaches.* Between the interface altitude and perigee altitude, the display is positive and increasing. When perigee is passed, R30 continues to display positive increasing time, except during AVERAGEG, when negative, decreasing time is displayed for ellipses. If AVERAGEG is off, keying VERB 32 ENTR to repeat R30 calculations also causes negative decreasing time to be displayed for ellipses.

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*The maximum display for TFF is ±59B59. Therefore, although the internal calculations may be counting down, the DSKY will continue to display ±59B59 until the value is less than one hour.

9.2.3.5 Procedures

When AVERAGEG is running, the astronaut keys in VERB 82 ENTR, and, if no other extended verb or priority display is running, R30 begins its computations and flashes VERB 16 NOUN 44. If P11 is running, the astronaut keys in NOUN 50 ENTR to obtain the estimate of splash error. During P40 maneuvers, the astronaut should key PRO to terminate R30 before the expected cutoff time, in order to allow important P40 displays to come up. (Extended verb displays have priority over non-priority program displays.)

When AVERAGEG is not running, the astronaut keys in VERB 82 ENTR. If no other extended verb is running, R30 flashes VERB 04 NOUN 12, requesting choice of vehicle. A PRO response indicates the CM is the assumed vehicle. A VERB 22 ENTR 2 ENTR response followed by PRO indicates the LM is the assumed vehicle. After the vehicle choice is made, R30 flashes VERB 06 NOUN 16, requesting the time of calculation validity. Initially, all zeros are displayed. A PRO response to all zeros in NOUN 16 indicates the astronaut desires the current time. To load a different time, the astronaut keys VERB 25 ENTR, loads the desired time in ground elapsed time (GET) and keys PRO, to obtain the flashing VERB 16 NOUN 44. Expected time of perigee is usually used when the current time is not desirable, for example, in the middle of transearth or translunar coast. If several times are to be used, the astronaut can recycle (VERB 32 ENTR, in response to flashing VERB 16 NOUN 44, 50, or 32) and load the new times into NOUN 16. If NOUN 44 indicates that the current orbit does not intersect the interface altitude (i.e., when R2 is greater than 49.4 n. mi. around the earth, or 5.8 n. mi. around the moon), the astronaut keys in NOUN 32, ENTR, to obtain the time to perigee.

If the CM is approaching entry and the current major mode is P00, the astronaut keys in NOUN 50 ENTR when VERB 16 NOUN 44 flashes, to get the estimate of splash error.

R30 can be terminated by keying PRO to the flashing VERB 16 NOUN 44, NOUN 50, or NOUN 32, or by selecting a new major mode.

9.2.3.6 Restrictions and Limitations

A flashing display from an extended verb, such as R30, takes priority over a flashing display from a major mode. The operation of R30, therefore, should be restricted to those times when important displays requiring immediate astronaut action are not expected.

During simulations, R30 has been known to cause bailout restarts (alarm codes 31201 or 31202) during periods of high computer activity. Some periods of high activity are during Lambert maneuvers, during P11, and when both P20 and a targeting program are running. These restarts are of little significance, except that R30 activity is terminated by the restart. If the crew still desires R30, they can reselect it. Since such restarts are often a matter of coincidence, reselection may not cause another restart.

The calculations used in R30 are conic. Thus, not only will these calculations produce meaningless results when the input time places the spacecraft in the middle of transearth or translunar coast, but in the following specific instances, they may result in a 21302 (square root negative number) POODOO restart:

1. From TEI +1.3 hours until sphere crossing (i.e., post-TEI, when the magnitude of the position vector is greater than 4333 n. mi.)
2. From the sphere crossing until LOI minus 3 hours (i.e., pre-LOI, when the magnitude of the position vector is greater than 7743 n. mi.).

9.2.3.7 Alarms

The OPR ERR light will illuminate if R30 is called when another extended verb is running. The alarms mentioned in paragraph 9.2.3.6 are the only ones expected during R30. They are as follows:

a. Alarm codes 31201 and 31202, a coreset overflow and a VAC area overflow, respectively. They may occur during operation of P11, P20, or P40/P41. Should they occur the crew can reselect R30.
b. Alarm code 21302, the square root of a negative number. This is caused by using the conic calculations in R30 with a time that places the spacecraft in the middle of transearth or translunar coast. Refer to paragraph 9.2.3.6. Recovery procedures are the reselection of R30 with a different time in NOUN 16. Since a NOUN 16 time is not available when AVERAGEG is running, R30 should not be selected during transearth or translunar midcourse maneuvers.

9.2.3.8 Restarts

R30 is not restart-protected. Should a restart occur, the astronaut must reselect the routine.

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9.2.4 R31, Rendezvous Parameter Display No. 1 Routine — CMC

VERB 83 ENTR initiates R31, which computes and displays the range and range rate between the CSM and the LM, and an angle θ, shown in Figure 9.2.4-1. The angle θ represents the angle between the CSM X-body axis and the local horizontal plane, referenced to the direction of flight. The computational sequence is illustrated in Figure 9.2.4-2.

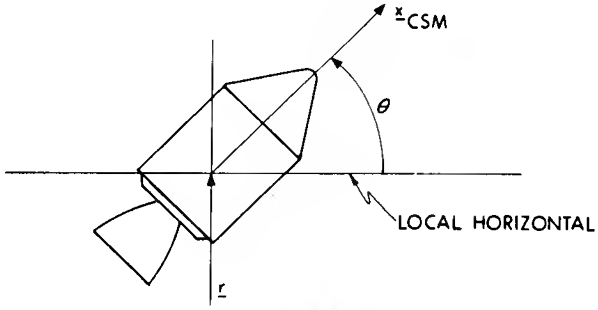

Figure 9.2.4-1 Definition of Theta

9.2.4.1 Input and Output

There is no astronaut input required for R31. The only output is a display of range, range rate and θ.

FL VERB 16 NOUN 54

R1	xxx.xx n. mi.	Range
R2	±xxxx.x ft/sec	Range rate
R3	xxx. xx deg	θ

9.2.4.2 Procedures

The crew keys in VERB 83 ENTR, and, if no other extended verb or priority display is running, R31 begins its computations and flashes VERB 16 NOUN 54. R31 then repeats the computations until the crew keys PRO or VERB 34 ENTR to terminate R31.

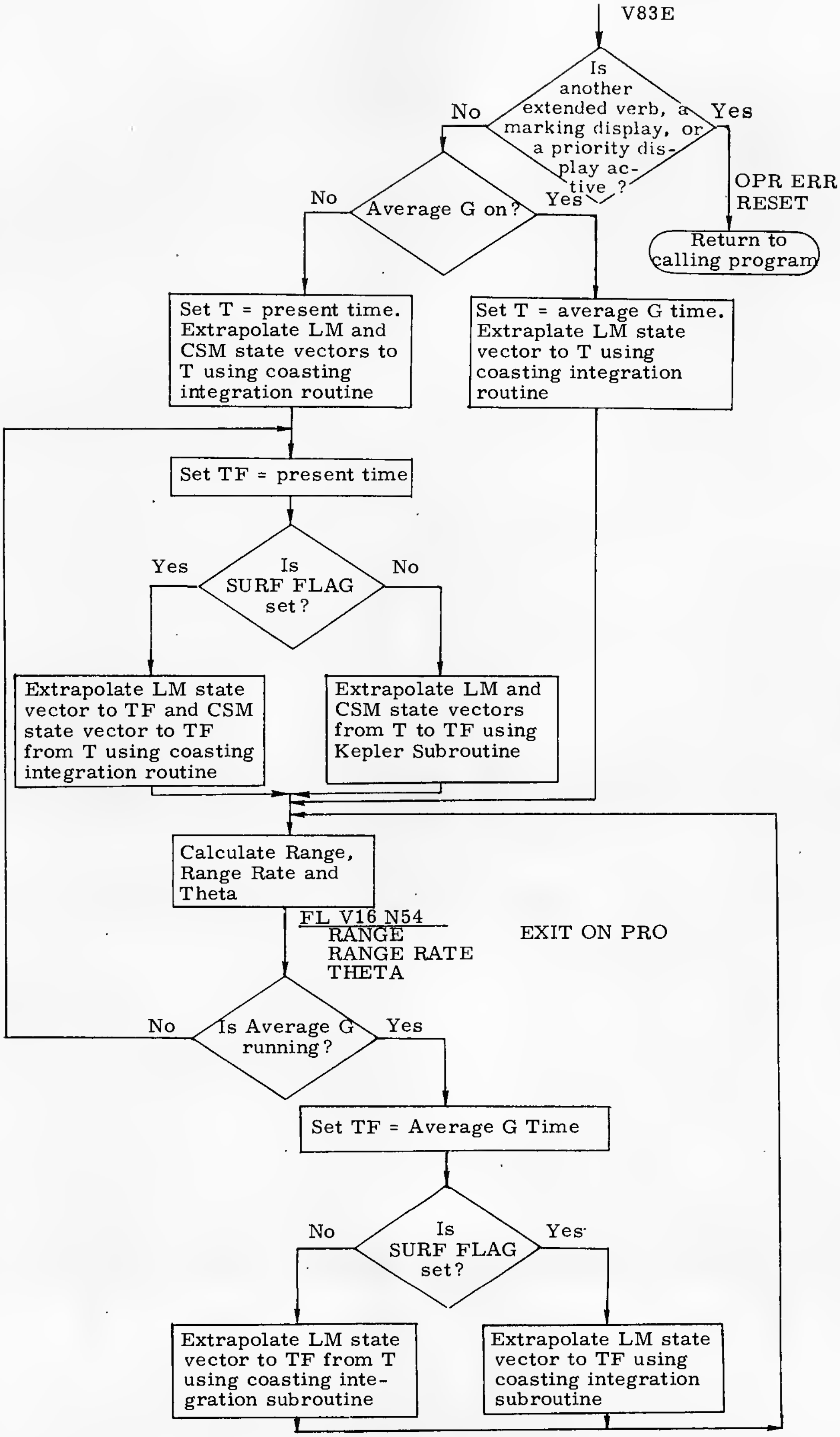

Figure 9.2.4-2. Rendezvous Parameter Display No. 1 Routine (R31)

9.2.5 R34, Rendezvous Parameter Display No. 2 Routine — CMC

VERB 85 ENTR initiates R34, which computes and displays the range and range rate between the CSM and the LM, and an angle ϕ shown in Figure 9.2.5-1. The angle ϕ represents the angle between the SXT line of sight and the local horizontal plane, referenced to the direction of flight. The computational sequence is illustrated in Figure 9.2.5-2.

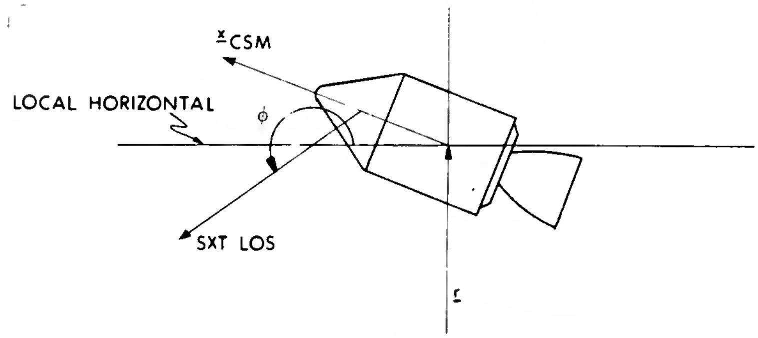

Figure 9.2.5-1 Definition of Phi

9.2.5.1 Input and Output

There is no astronaut input required for R34. The only output is a display of range, range rate and ϕ.

FL VERB 16 NOUN 53

R1	xxx.xx n.mi.	Range
R2	±xxxx.x ft/sec	Range rate
R3	xxx.xx deg	ϕ

9.2.5.2 Procedures

The crew keys in VERB 85 ENTR, and, if no other extended verb or priority display is running, R34 begins its computations and flashes VERB 16 NOUN 53. R34 then repeats the computations until the crew keys PRO or VERB 34 ENTR to terminate R34.

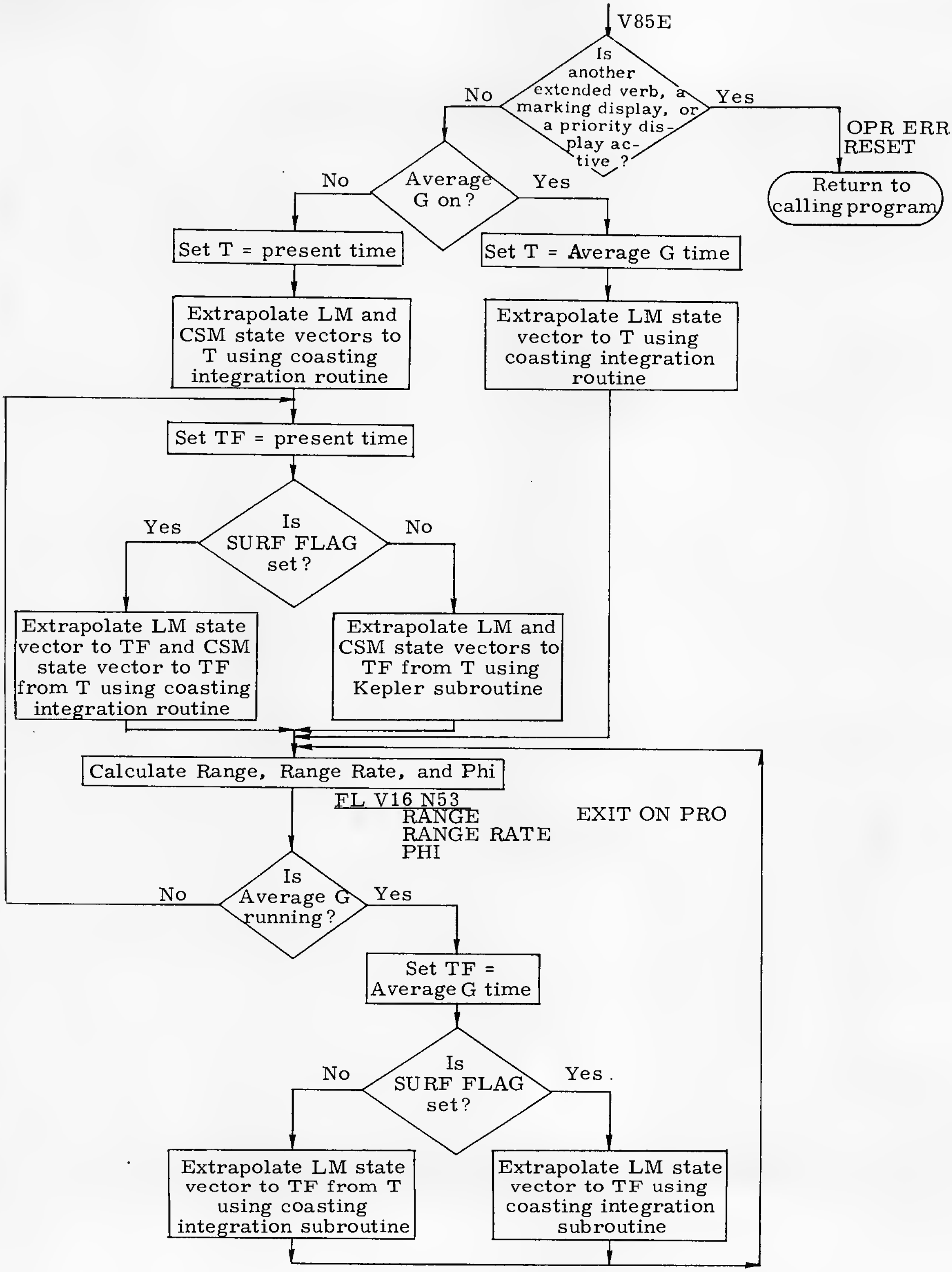

Figure 9.2.5-2. Rendezvous Parameter Display No. 2 Routine (R34)

9.2.6 R36, Rendezvous Out-of-plane Display—CMC

R36 computes and displays parameters related to the out-of-plane characteristics of the current orbital configuration, and allows the astronaut to target maneuvers designed to achieve coplanar orbits.* Such maneuvers might be targeted by the following programs:

a. P30—targets out-of-plane maneuvers not timed with the typical rendezvous sequence maneuvers.
b. P34—targets transfer phase initiation (TPI) maneuvers.
c. P35—targets transfer phase midcourse (TPM) maneuvers.

The routine calculates the parameters on the basis of the stored LM and CSM state vectors, and the time at which the calculations are to be valid—specified time, or T(EVENT)—.

Using these inputs, R36 computes and displays the following:

1. Out-of-plane position of the CSM relative to the LM orbital plane Y(CM).
2. Out-of-plane velocity of the CSM relative to the LM orbital plane Y-dot (CM).
3. Out-of-plane velocity of the LM relative to the CSM orbital plane Y-dot (LM).

For the astronaut, the most significant of these displays is Y-dot (CM), the CSM out-of-plane velocity, because it allows him to target for a coplanar orbit. Each of the targeting programs listed above displays the $\Delta \underline{v}$(LV) for the astronaut's approval or modification. The astronaut then loads the negative of the Y-dot into the Y component (register 2) of the $\Delta \underline{v}$(LV) display. This value is designed to produce a node 90 deg later. If the out-of-plane velocity (Y-dot) of the assumed vehicle is nulled at a particular point by thrusting an equal Δv in the opposite direction, then that point becomes an antinode, and 90 deg later, a node will occur. If the out-of-plane velocity is then nulled at the node, the two orbits become coplanar. (A more detailed explanation of the orbital mechanics involved in out-of-plane maneuvers is included in the introduction to the targeting programs, subsection 5.1.)

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*In general, it is desirable to carry out a rendezvous under circumstances in which the LM and the CSM orbits are coplanar.

9.2.6.1 Inputs and Outputs

As mentioned above, R36 calculates the parameters displayed using one astronaut input, the time at which the calculations are to be valid. If the astronaut desires the present time, as he might during P35, he can indicate the present time by supplying all zeros for the time.

The outputs of R36 are displayed via flashing VERB 06 NOUN 96. Inputs and outputs to R36 are listed in Tables 9.2.6-I and 9.2.6-II, respectively. Note that, since the desire is to null out the Y, the crew must change the sign when loading Y-dot into R2 of the $\Delta \underline{v}$(LV) targeting display. Figure 9.2.6-1 presents a flowchart of R36.

9.2.6.2 Computational Sequence

When the astronaut keys in R36, via VERB 90 ENTR, the CMC first checks to determine if any other extended verb or priority display is running . If so, R36 is terminated, and the OPR ERR light illuminates to inform the astronaut that R36 has terminated. The astronaut must then terminate the other extended verb, so that R36 can be activated.

If no other extended verb is active, R36 flashes VERB 06 NOUN 16 requesting T(EVENT). T(EVENT) is first displayed as the current value stored into the registers containing t_{IG}. This will either be the t_{IG} of the last maneuver or target Δv, or that of the next maneuver. If that is not the desired time, T(EVENT) should be loaded in ground elapsed time (GET). If the present time is desired, all zeros should be loaded.

Then, the CMC extrapolates the state vectors to the indicated time, and computes the parameters to be displayed. The parameters are displayed via a flashing VERB 06 NOUN 96 display. If the astronaut responds to the flashing VERB 06 NOUN 96 display with a VERB 32 ENTR, R36 will recycle, allowing a different time to be entered into NOUN 16. If the astronaut responds to the flashing VERB 06 NOUN 96 with a PRO, the routine terminates.

9.2.6.3 Restrictions and Limitations

R36 cannot be used when another extended verb is active. R36 should not be called while AVERAGEG is running. Should this occur, the information displayed by R36 will probably be inaccurate.

9.2.6.4 Restarts

R36 is not restart protected. Should a restart occur while R36 is operating, R36 must be reselected.

9.2.6.5 Coordination

R36 may be run at any time (with the restrictions given above). The ISS need not be running or aligned for R36.

TABLE 9.2.6-I

RENDEZVOUS OUT-OF-PLANE DISPLAY ROUTINE
(CSM R36) INPUTS

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time when display parameters are to be valid	T(EVENT)	FL V06 N16	R1 ooxxx. hrs R2 oooxx. min R3 oxx. xx sec	Astronaut should load desired time in GET, unless he desires the present time, in which case, he should load all zeros.

TABLE 9.2.6-II

RENDEZVOUS OUT-OF-PLANE DISPLAY ROUTINE (CSM R36) OUTPUTS

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Distance CSM is from plane of LM at T(EVENT)	Y (CM)	FL V06 N96	R1 xxx.xx n.mi.	
2.	Out-of-plane velocity of the CSM relative to the LM orbital plane	$\dot{Y}$ (CM)	FL V06 N96	R2 xxxx.x fps	
3.	Out-of-plane velocity of the LM relative to the CSM orbital plane	$\dot{Y}$ (LM)	FL V06 N96	R3 xxxx.x fps	

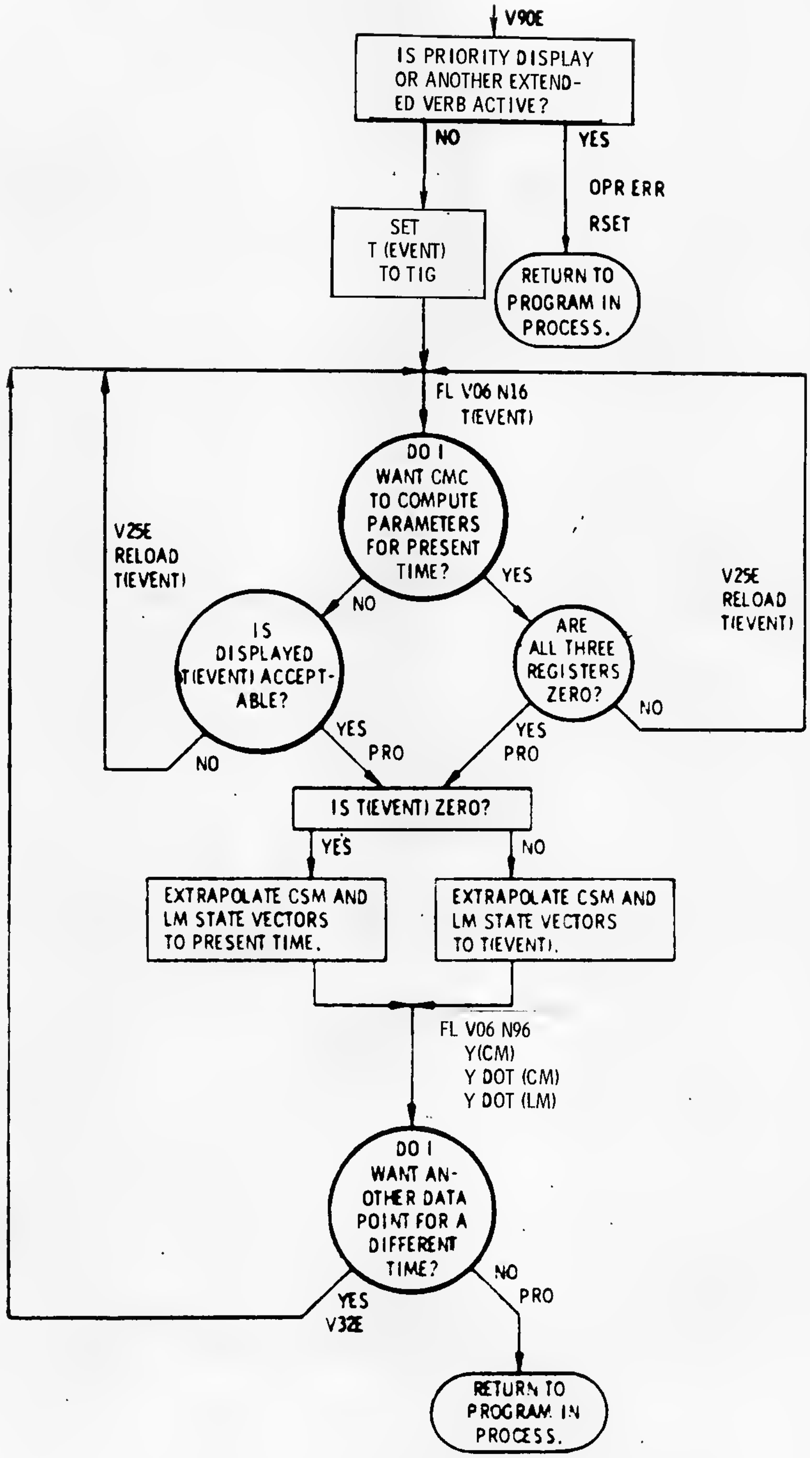

Figure 9.2.6-1. Rendezvous Out-of-plane Display Routine (CSM R36)

SUBSECTION 9.3

ADDITIONAL LGC EXTENDED VERB ROUTINES

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9.3.1 R03, Digital Autopilot (DAP) Data Load—LGC

This paragraph will be supplied for Revision 4 at a later date.

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9.3.2 R30, Orbital-parameters Display—LGC

VERB 82 ENTR initiates R30, which computes and displays orbital parameters. The parameters computed by R30 can be used to monitor the progress of thrusting maneuvers, or to check the current orbit during coasting flight.

9.3.2.1 Inputs

If AVERAGEG is running—i.e., during powered flight—there are no astronaut inputs to R30. The routine simply uses the current state vector, as updated by AVERAGEG, to calculate the displayed parameters. If AVERAGEG is not running—i.e., during coasting flight—the astronaut inputs the choice of vehicle, LM or CM.

R30 inputs are described in Table 9.3.2-I.

9.3.2.2 Outputs

The following parameters are always computed:

1. Apogee altitude
2. Perigee altitude
3. Time of free fall to the orbital interface* (TFF), or
4. Time from perigee, TPER, if the current orbit does not intersect the orbital interface.

R30 outputs are described in Table 9.3.2-II.

9.3.2.3 Options

The options discussed in this paragraph are as follows:

1. Choice of vehicle
2. Choice of NOUN to monitor

If AVERAGEG is running, the astronaut has no choice of vehicle; the LM is always the vehicle for which the parameters are calculated. Otherwise, the choice of vehicle clearly depends on which vehicle's orbital parameters the astronaut needs.

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*The orbital interface is 35,000 feet above the landing site radius (RLS) in lunar orbit, and 300,000 feet above launch pad radius in earth orbit.

TABLE 9.3.2-I

ORBITAL-PARAMETERS DISPLAY ROUTINE (LM R30) INPUT*

DSKY	Initiated By	Purpose	Condition	Register
FL V04 N12	R30	Assumed vehicle code. R2 initially displays 00001, indicating LM. VERB 22 ENTR 2 ENTR indicates CM is to be assumed vehicle.	Request astronaut to indicate assumed vehicle	R1 00002 R2 oooox

*No astronaut input is required when AVERAGEG is running.

TABLE 9.3.2-II

ORBITAL-PARAMETERS DISPLAY ROUTINE (LM R30) OUTPUTS

DSKY	Initiated By	Purpose	Condition	Register
FL V16 N44	R30	These apsidal altitudes measured above launch pad radius, when in the earth's sphere, and above the latest landing site, when in the moon's sphere.	Apogee altitude Perigee altitude	R1 xxxx.x n.mi.* R2 xxxx.x n.mi.*
		Once computed, counts down. Sign convention is in text.	Time to interface altitude (free fall)	R3 xxBxx min, sec
NOUN 32 ENTR (keyed after FL VERB 16 indicates R30 calculations are completed)	Astronaut	Computed when current orbit does not intersect the interface altitude, and then counts down. Set to zero otherwise.	Time to perigee (free fall)	R1 ooxxx. hrs R2 oooxx. min R3 oxx.xx sec

*These registers are limited to 9999.9 n.mi.

The astronaut can monitor two nouns, NOUN 44 and NOUN 32. In most cases, NOUN 44, which R30 flashes automatically, gives all the information computed by R30; it contains apogee altitude, perigee altitude, and time of free fall to the interface altitude. An exception is when the current orbit does not intersect the interface altitude. Then R30 calculates the time of free fall to perigee in hr, min, and sec; this display can be called in NOUN 32.

9.3.2.4 Computational Sequence

Figure 9.3.2-1 illustrates the computational sequence of R30. After the astronaut selects R30, via VERB 82 ENTR, R30 determines whether another extended verb or priority display is active. If so, R30 illuminates the OPR ERR light and terminates. If the astronaut still desires R30, he must terminate the other extended verb and reselect R30.

If no other extended verb or priority display is operating, R30 next determines whether AVERAGEG is running. If so, R30 calculations are updated about every 2 seconds. If not, the calculations are performed once and the displayed times are made to count down.

9.3.2.4.1 R30 AVERAGEG Calculations.—During AVERAGEG operation, R30 begins calculation of the outputs listed in paragraph 9.3.2.2 as soon as the LM computer can schedule them—that is, as soon as AVERAGEG is completed for the current cycle. R30 uses the current state vector and its associated time, updates its calculations approximately every two seconds, depending on the availability of computer time, and flashes the results in a VERB 16 NOUN 44 display. R30 automatically terminates when AVERAGEG terminates (i.e., at selection of a new program). If the astronaut wishes to terminate R30 before AVERAGEG terminates, he can respond to the flashing VERB 16 NOUN 44 with a PRO.

9.3.2.4.2 R30 Coasting Flight Calculations.—If AVERAGEG is not running, the astronaut must supply R30 with the choice of vehicle. Accordingly, R30 flashes VERB 04 NOUN 12, requesting choice of vehicle. After a PRO response to this display, R30 uses Coasting Integration to obtain the orbit at the current time, and begins calculations of the orbital parameters. If the current orbit intersects the interface altitude, R30 calculates TFF, sets TPER to zero, and begins counting down. If the current orbit does not intersect the interface altitude, R30 sets TFF to -59B59, calculates TPER, and begins counting down. A PRO response to flashing VERB 16 NOUN 44 terminates R30.

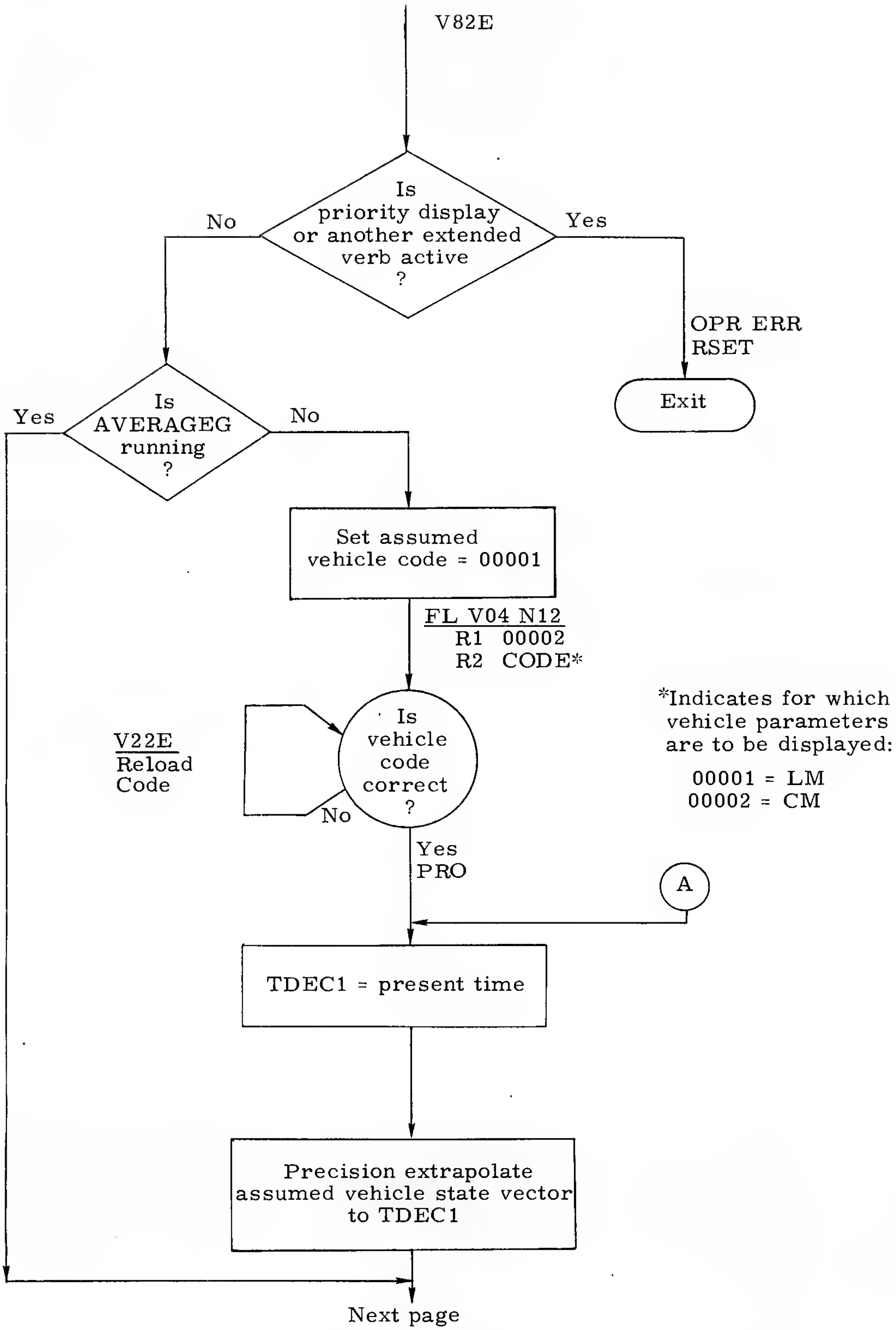

Figure 9.3.2-1. Orbital-parameters Display Routine (LM R30) (Sheet 1 of 2)

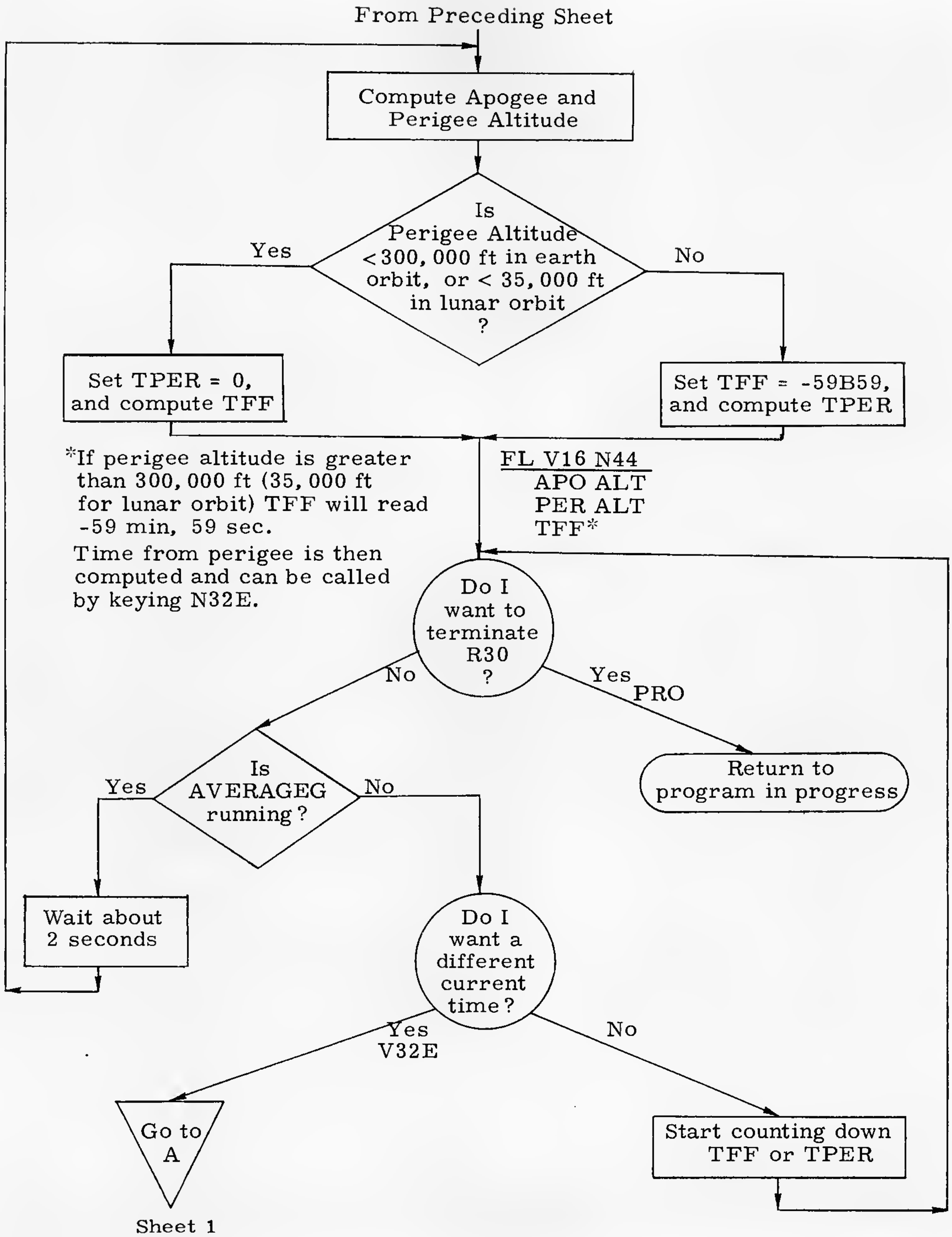

Figure 9.3.2-1. Orbital-parameters Display Routine (LM R30) (Sheet 2 of 2)

9.3.2.4.3 Sign Conventions.—The sign convention for TFF and TPER is as follows: the DSKY display is negative and decreasing (in magnitude) as the interface altitude approaches.* Between the interface altitude and perigee altitude, the display is positive and increasing. When perigee is passed, R30 continues to display positive increasing time, except during AVERAGEG, when negative decreasing time is displayed for ellipses. If AVERAGEG is off, keying VERB 32 ENTR to repeat R30 calculations also causes negative decreasing time to be displayed for ellipses.

9.3.2.5 Procedures

When AVERAGEG is running, the astronaut keys in VERB 82 ENTR, and, if no other extended verb or priority display is running, R30 begins its computations and flashes VERB 16 NOUN 44. During P40 or P42 maneuvers, the astronaut should key PRO to terminate R30 before the expected cutoff time in order to allow important P40 or P42 displays to come up. (Extended verb displays have priority over non-priority program displays.)

When AVERAGEG is not running, the astronaut keys in VERB 82 ENTR. If no priority display or extended verb is running, R30 flashes VERB 04 NOUN 12, requesting choice of vehicle. A PRO response indicates the LM is the assumed vehicle. A VERB 22 ENTR 2 ENTR response followed by PRO indicates the CM is the assumed vehicle. After the vehicle choice is made, the astronaut will observe the flashing VERB 16 NOUN 44. If NOUN 44 indicates that the current orbit does not intersect the interface altitude (i.e., when R2 is greater than 49.4 n. mi. around the earth, or 5.8 n. mi. around the moon), the astronaut can key in NOUN 32 ENTR, to obtain the time to perigee.

R30 can be terminated by keying PRO to the flashing VERB 16 NOUN 44 or NOUN 32, or by selecting a new major mode.

9.3.2.6 Restrictions and Limitations

A flashing display from an extended verb, such as R30, takes precedence over a non-priority flashing display from a major mode. The operation of R30, therefore, should be restricted to those times when important displays requiring immediate astronaut action are not expected.

*The maximum display of TFF is ±59B59. Therefore, although the internal calculations may be counting down, the DSKY will continue to display ±59B59 until the value is less than one hour.

During simulations, R30 has been known to cause bailout restarts (alarm codes 31201 or 31202) during periods of high computer activity. Some periods of high activity are during Lambert maneuvers, and when both P20 and a targeting program are running. These restarts are of little significance, except that R30 activity is terminated by the restart. If the crew still desires R30, he can reselect it. Since such restarts are often a matter of coincidence, reselection may not cause another restart.

The calculations used in R30 are conic. Thus, not only will these calculations produce meaningless results when the spacecraft is in the middle of a transearth or translunar coast, but in the following specific instances, they may result in a 21302 (square root negative number) POODOO restart:

1. From TEI +1.3 hours until sphere crossing (i.e., post-TEI, when the magnitude of the position vector is greater than 4333 n. mi.)
2. From the sphere crossing until LOI minus 3 hours (i.e., pre-LOI, when the magnitude of the position vector is greater than 7743 n. mi.).

9.3.2.7 Alarms

The OPR ERR light will illuminate if R30 is called when a priority display or another extended verb is running. The alarms mentioned in paragraph 9.3.2.6 are the only ones expected during R30. They are as follows:

a. Alarm codes 31202 and 31201, a coreset overflow and a VAC area overflow, respectively. They may occur during operation of P20, or P40/P41/P42. Should they occur, the crew can reselect R30.
b. Alarm code 21302, the square root of a negative number. This is caused by using the conic calculations in R30 when the spacecraft is in the middle of transearth or translunar coast. Refer to paragraph 9.3.2.6. R30 should <u>not</u> be selected during transearth or translunar midcourse maneuvers.

9.3.2.8 Restarts

R30 is not restart-protected. Should a restart occur, the astronaut must reselect the routine.

9.3.3 R36, Rendezvous Out-of-plane Display—LGC

R36 computes and displays parameters related to the out-of-plane characteristics of the current orbital configuration, and allows the astronaut to target maneuvers designed to achieve coplanar orbits.* Such maneuvers might be targeted by the following programs:

a. P30—targets out-of-plane maneuvers not timed with the typical rendezvous sequence maneuvers.
b. P34—targets transfer phase initiation (TPI) maneuvers.
c. P35—targets transfer phase midcourse (TPM) maneuvers.

The routine calculates the parameters on the basis of the stored LM and CSM state vectors, and the time at which the calculations are to be valid—specified time, or T(EVENT).

Using these inputs, R36 computes and displays the following:

1. Out-of-plane position of the LM relative to the CM orbital plane, Y(LM).
2. Out-of-plane velocity of the LM relative to the CM orbital plane, Y-dot (LM).
3. The angle ψ, where ψ is the angle between the line of sight and the forward direction, measured in the local horizontal plane. It is equivalent to the yaw angle on the FDAI ball if the ball were aligned to an inplane, local horizontal attitude and the vehicle were rotated such that the Z-axis were pointed along the line of sight.

For the astronaut, the most significant of these displays is Y-dot (LM), the LM out-of-plane velocity, because it allows him to target for a coplanar orbit. Each of the targeting programs listed above displays the $\Delta \underline{v}$(LV) for the astronaut's approval or modification. The astronaut then loads the negative of the Y-dot into the Y component (register 2) of the $\Delta \underline{v}$(LV) display. This procedure will produce a node 90 deg later for the following reasons. If the out-of-plane velocity (Y-dot) of the assumed vehicle is nulled at a particular point by thrusting an equal Δv in the opposite direction, then that point becomes an antinode, and 90 deg later, a node will occur. If the out-of-plane velocity is then nulled at the node, the two orbits become coplanar. (A more detailed explanation of the orbital mechanics involved in out-of-plane maneuvers is included in the introduction to the targeting programs, subsection 5.1.)

*In general, it is desirable to carry out a rendezvous under circumstances in which the LM and the CSM orbits are coplanar.

9.3.3.1 Inputs and Outputs

As mentioned above, R36 calculates the parameters displayed using one astronaut input, the time at which the calculations are to be valid. If the astronaut desires the present time, as he might during P35, he can indicate the present time by supplying all zeros for the time.

The outputs of R36 are displayed via flashing VERB 06 NOUN 90. Inputs and outputs to R36 are listed in Tables 9.3.3-I and 9.3.3-II, respectively. Note that, since the desire is to null out the Y, the crew must change the sign when loading Y-dot into R2 of the $\Delta \underline{v}$(LV) targeting display. Figure 9.3.3-1 presents a flowchart of R36.

9.3.3.2 Computational Sequence

When the astronaut keys in R36, via VERB 90 ENTR, the LGC first checks to determine if any other extended verb or priority display is running or if AVERAGEG is active. If so, R36 is terminated, and the OPR ERR light illuminates to inform the astronaut that R36 has terminated. The astronaut must then terminate the other extended verb or thrusting program, so that R36 can be activated.

If no other extended verb or priority display is active, R36 flashes VERB 06 NOUN 16 requesting T(EVENT). T(EVENT) is first displayed as the current value stored in the registers containing t_{IG}. This will be the t_{IG} either of the last maneuver or target Δv, or of the next maneuver. If the t_{IG} is not the desired time, T(EVENT) should be loaded in ground elapsed time (GET). If the present time is desired, all zeros should be loaded.

Then, the LGC extrapolates the state vectors to the indicated time, and computes the parameters for that time. The parameters are displayed via a flashing VERB 06 NOUN 90 display. If the astronaut responds to the flashing VERB 06 NOUN 90 display with a VERB 32 ENTR, R36 recycles, allowing a different time to be entered into NOUN 16. If the astronaut responds to the flashing VERB 06 NOUN 90 with a PRO or VERB 34 ENTR, the routine terminates.

9.3.3.3 Restrictions and Limitations

R36 cannot be used when another extended verb is active or while AVERAGEG is running.

TABLE 9.3.3-I

RENDEZVOUS OUT-OF-PLANE DISPLAY ROUTINE
(LM R36) INPUTS

Input	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Time when display parameters are to be valid	T(EVENT)	FL V06 N16	R1 ooxxx. hrs R2 oooxx. min R3 oxx.xx sec	Astronaut should load desired time in GET, unless he desires the present time, in which case, he should load all zeros.

TABLE 9.3.3-II

RENDEZVOUS OUT-OF-PLANE DISPLAY ROUTINE (LM R36) OUTPUTS

Output	Identification	Display Mnemonic	DSKY	Register	Comments
1.	Distance LM is from plane of CM at T(EVENT)	Y(LM)	FL V06 N90	R1 xxx.xx n. mi.	
2.	Out-of-plane velocity of the LM relative to the CSM orbital plane	$\dot{Y}$(LM)	FL V06 N90	R2 xxxx.x fps	
3.	Angle between line of sight and the forward direction, measured in the local horizontal plane	PSI	FL V06 N90	R3 xxx.xx deg	

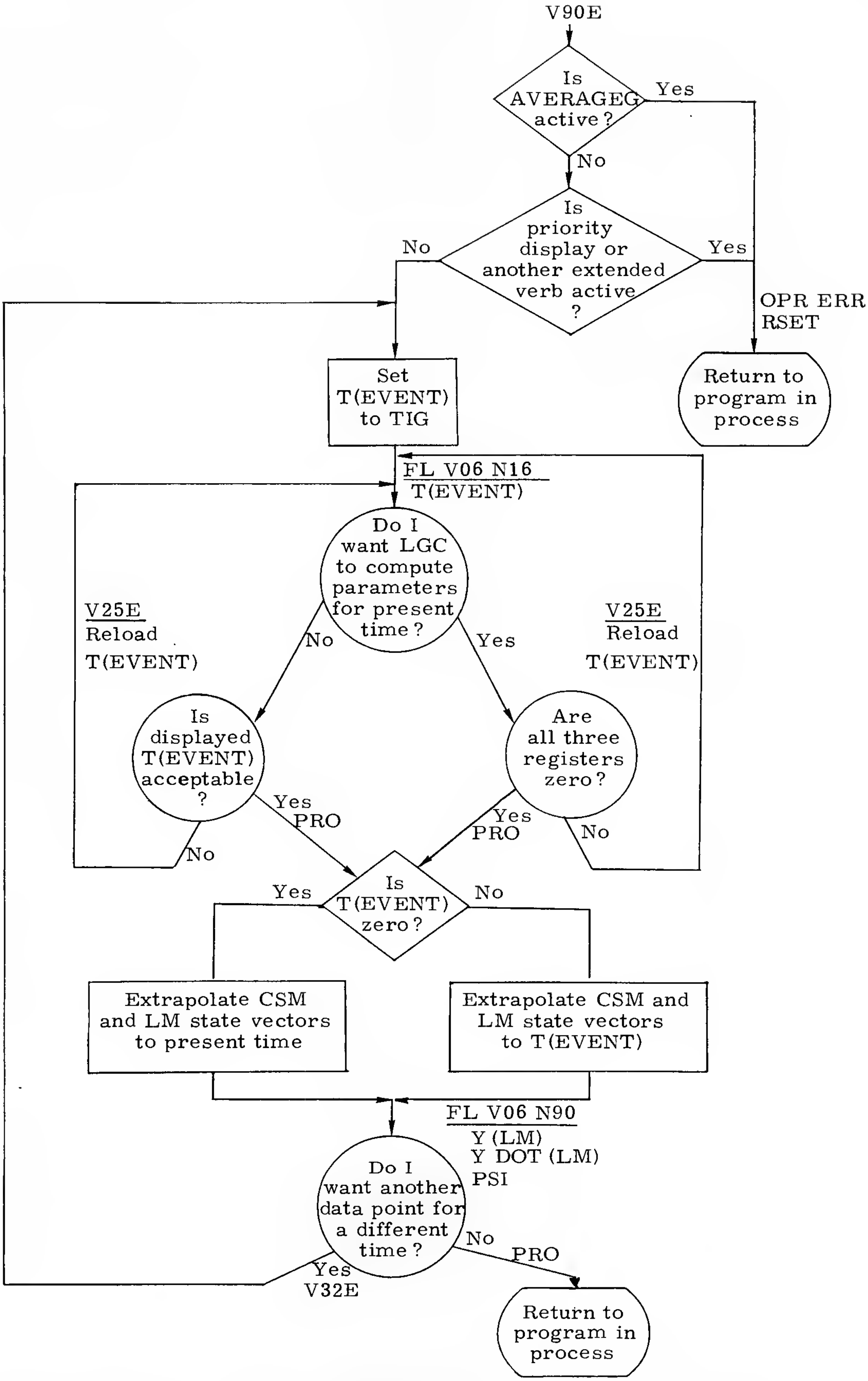

Figure 9.3.3-1. Rendezvous Out-of-plane Display Routine (LM R36)

9.3.3.4 Restarts

R36 is not restart protected. Should a restart occur while R36 is operating, R36 must be reselected.

9.3.3.5 Coordination

R36 may be run at any time (with the restrictions given above). The ISS need not be running or aligned for R36.

9.3.4 R63, Rendezvous Final-attitude Routine—LGC

This routine provides a means of calculating the final FDAI ball angles for an attitude maneuver to an appropriate LM orientation. When the gimbal angles have been calculated, the routine calls the Attitude Maneuver Routine (R60) for a PGNCS-controlled attitude maneuver. Time can be saved, therefore, by setting the GUID CONT switch to PGNS before R63 is called. For automatic maneuvers, Routine R03 must be performed before R63 is called; the PGNS MODE CONTROL switch must be placed in AUTO. Routine R63 can only be called from P00 or a fresh start condition.

Keying VERB 89 ENTR, the crew observes an immediate flashing VERB 04 NOUN 12 (Figure 9.3.4-1) unless one of the following error or alarm conditions exists:

1. If the current program is not P00 or a fresh start condition, or if another extended verb is active, the DSKY OPR ERR light illuminates.
2. If the IMU is not on and aligned to an orientation known by the LGC, the IMU Status Check Routine (R02) generates a PROG alarm.

Assuming no error or alarm condition, register R1 of the VERB 04 NOUN 12 display will contain the code (00003) designating assumed tracking attitude; register R2 will contain the option code (00001) for the "preferred" tracking axis (Z-axis); register R3 will be blank. The appropriate final rendezvous tracking attitude might not be the "preferred," however, but the LM X-axis pointed at the CM. In this case, before keying PRO the crew must key VERB 22 ENTR and load option code 00002 in register R2. PRO then causes R63 to extrapolate the CSM and LM state vectors to the present +1 minute, calculate the appropriate LM attitude, and compute the required FDAI ball angles. The ball angles are then displayed by a flashing VERB 06 NOUN 18. If the crew is satisfied with the angles displayed and wishes the PGNCS to control the maneuver, he keys PRO, which causes the Attitude Maneuver Routine (R60) to be called. Otherwise, the crew either can key VERB 32 ENTR to recycle R63 for a later solution or can terminate R63 by keying VERB 34 ENTR. In the nominal condition, the maneuver to point the LM at the CM is completed in R60; R63 then exits. R63 is not restart protected. Should a restart occur while R63 is operating, R63 must be reselected.

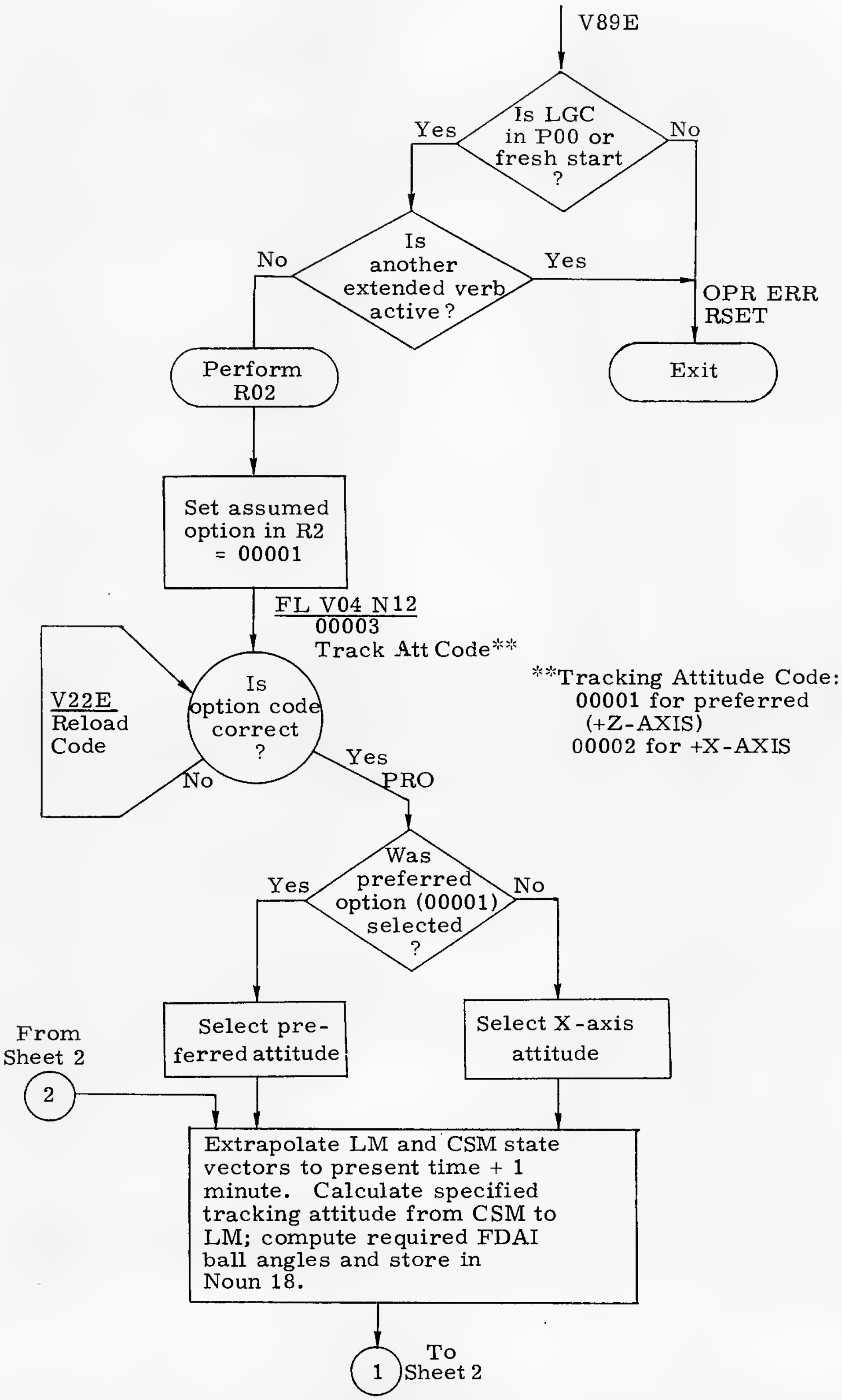

Figure 9.3.4-1. Rendezvous Final-attitude Routine (LM R63) (Sheet 1 of 2)

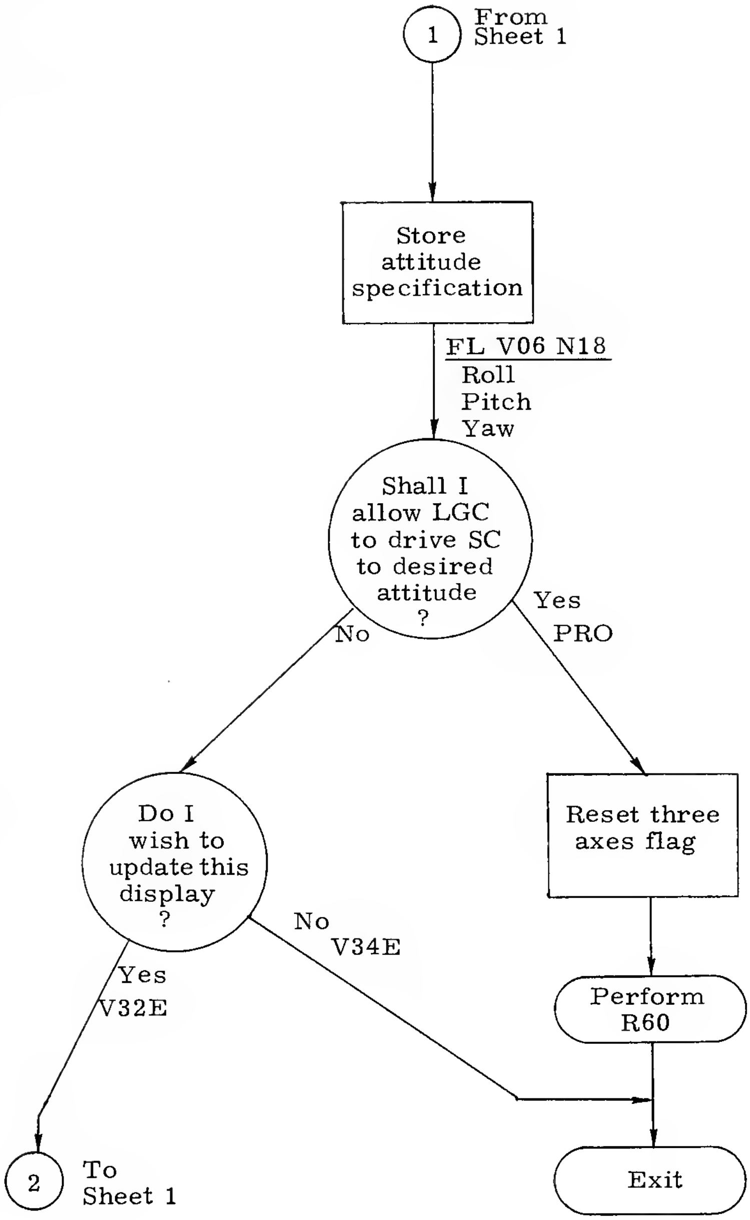

Figure 9.3.4-1. Rendezvous Final-attitude Routine (LM R63) (Sheet 2 of 2)

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9.3.5 R77, Landing Radar Spurious Test Routine—LGC

This paragraph will be supplied for Revision 4 at a later date.

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9.3.6 R05, S-Band Antenna Routine—LGC

This paragraph will be supplied for Revision 4 at a later date.

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SECTION 10.0

EXTENDED VERBS

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10.1 INTRODUCTION

Extended Verbs (those verbs numbered 40 through 99) are provided as a means of enabling the crew to select by DSKY entry a number of special routines, functions, and displays. The crew selects the extended verb by keying VERB xx ENTR.* The purpose of each of the extended verbs is given in the paragraph describing that verb.

Subsection 10.2 contains the extended verb descriptions for the CMC; subsection 10.3 contains those for the LGC. The following extended verbs are unused and, if selected by the crew, cause the OPR ERR DSKY light to be illuminated:

- CMC Verbs 68, 76, 77, 79, 84, 92, 95 and 98
- LGC Verbs 45, 46, 51, 84, 86, 87, 88, 94 and 98.

These verbs are omitted in subsections 10.2 and 10.3.

Also omitted are those verbs which, although numbered between 40 and 99, are used only for program-generated displays and should not be selected by the crew. They are as follows:

- CMC Verbs 50, 51, 53, 59, 77, and 99
- LGC Verbs 50, 52, 53, 54, 97, and 99.

Extended verbs which initiate DSKY displays are prevented from conflicting with each other by means of an extended verb interlock. When this interlock is set, other extended verbs which use the DSKY are locked out. Each of these verbs sets the interlock when activated and resets it before exiting. The interlock is also set during priority displays and "PLEASE MARK" displays for optics, COAS, and AOT marking routines to prevent display conflicts between the marking or priority displays and extended verb displays.**

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*In the LGC, VERB 40 and 41 require either NOUN 20 or NOUN 72 to distinguish between IMU and Rendezvous Radar, e.g., Verb 40 NOUN 72 zeroes the Rendezvous Radar CDUs. In the CMC, VERB 41 requires either NOUN 20 or NOUN 91 to distinguish between the IMU and the Optics System.

**All references in subsections 10.2 and 10.3 to interlock due to extended verbs are meant to include the lockout by marking or priority displays as well.

rather than a POODOO abort is performed by the program.* This has the effect of terminating the extended verb and restarting the current major mode, thus ensuring that the main mission program is not aborted due to an alarm condition generated by an extended verb.

Since the selection of an extended verb by the crew causes at least one additional job to be scheduled by the Executive, BAILOUT restarts due to executive overflow (alarm codes 31201 or 31202) may occur when extended verbs are selected during periods of high computer activity. These restarts terminate the extended verb. Reselection of the extended verb may be possible without causing another restart, since the executive overflow condition is usually correctable by a change in job-request timing.

Displays initiated by extended verbs take precedence over non-priority displays initiated by a major mode. Therefore, when important non-priority major mode displays are expected, it is unwise to select extended verbs which initiate displays. Priority displays (such as FL VERB 06 NOUN 49 in P20) take precedence over extended verb displays and will replace them on the DSKY. When the priority display is answered, the extended verb display will return to the DSKY.

None of the extended verb routines or functions is restart protected.** Should a restart occur during its execution, the extended verb procedure must be repeated.

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*The software generates POODOO aborts when non-recoverable errors are encountered; e.g., an attempt to take the square root of a negative number, or to integrate a sub-surface state vector.

**An exception is P27, initiated by Verb 70-Verb 73. (See paragraph 4.2.5.6.)

SUBSECTION 10.2

CMC EXTENDED VERBS

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10.2.1 Verb 40

Extended Verb 40 zeroes the Inertial Measurement Unit (IMU) CDUs. The process can be selected by the crew if the Inertial Subsystem (ISS) is not in the coarse align mode and gimbal lock. Refer to paragraph 7.2.2.7, Table 7.2.2-II, and Figure 7.2.2-13 for details.

10.2.2 Verb 41 Noun 20

Extended Verb 41 (Noun 20) coarse aligns the Inertial Measurement Unit (IMU). If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 7.2.2.7, Table 7.2.2-II, and Figure 7.2.2-10 for details.

10.2.3 Verb 41 Noun 91

Extended Verb 41 (Noun 91) coarse aligns the Optics Subsystem (OSS). Unless a fresh start situation exists (blank major mode) or P00 is operating, the process will not be initiated and the OPR ERR DSKY light will be illuminated. If the extended verb interlock has been set by a currently operating extended verb, or if the Optics mode switch is not CMC, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 7.2.2.7, Table 7.2.2-II, Figure 2.2.1-8, and Figure 7.2.2-11 for details.

10.2.4 Verb 42

Extended Verb 42 fine aligns the Inertial Measurement Unit (IMU) by torquing the gyros. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. This process is primarily intended for ground testing. Refer to paragraph 7.2.2.7, Table 7.2.2-II and Figure 7.2.2-12 for details.

10.2.5 Verb 43

Extended Verb 43 enables the astronaut to specify angles for the FDAI error needles. If a fresh start situation does not exist (major mode not blank), and if P00 is not

operating, or if the IMU is not in the fine align mode, the process will not be initiated and the OPR ERR DSKY light will be illuminated. After liftoff,* if the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated; before liftoff, other extended verbs will be overridden by selection of this process. After liftoff,* the extended verb interlock is set by this process. Refer to paragraph 2.2.1.4.3.2 and Figure 2.2.1-6 for a description of the procedure..

10.2.6 Verb 44

Extended Verb 44 sets SURFFLAG, indicating to the CMC that the LM is on the lunar surface. If this flag is set, the LM state vector will not be integrated, and RLS will be used in determining LM position. Refer to Table 4.2.1-III.

10.2.7 Verb 45

Extended Verb 45 resets SURFFLAG, indicating to the CMC that the LM is not on the lunar surface. Refer to Table 4.2.1-III.

10.2.8 Verb 46

Extended Verb 46 is executed to establish autopilot control of the spacecraft (Verb 48 (R03) should previously have been completed). If the TVC DAP is not operational and the configuration digit (from R03, digit A of R1 of Noun 46) is 1 (CSM only), 2 (CSM–LM, i.e., CSM docked with a complete LM, ascent and descent stages), or 6 (CSM–LM, i.e., CSM docked with LM, ascent stage only) the RCS DAP will begin initialization. This will occur even if the RCS DAP is already running. If the IMU is on and useable, the RCS DAP is fully operational within 1.7 seconds. If the TVC DAP is on and the vehicle configuration is not CSM–LM, then the OPR ERR light on the DSKY panel is illuminated. If the TVC DAP is on and the vehicle configuration is CSM–LM, then the stability filter, primarily for slosh frequency oscillations, is changed from high band-width to low band-width. If the TVC DAP is not on and the vehicle configuration is 0 (no DAP), the present DAP is turned off. If the TVC DAP is not on and the vehicle configuration is 3, the Saturn DAP is enabled. The Saturn DAP allows rotational hand controller (RHC) commands to be available to the SIV-B autopilot and steering jets for manual rate control.

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* Liftoff is indicated by channel discrete or backup liftoff flagbit. (See Verb 75, paragraph 10.2.32)

During TVC operation, execution of Verb 46 does not affect the RCS DAP since it is not operational. During Entry, execution of Verb 46 will have no effect since the Entry DAP sets the vehicle configuration to 0.

10.2.9 Verb 47

Extended Verb 47 is used to transfer the LM state vector information to the CSM state vector registers. Verb 47 is callable any time; but when AVERAGEG integration is operational, i.e., during a powered flight program, Verb 47 should not be selected, since there is danger of destroying the CSM state vector. See also Verb 66 (paragraph 10.2.24).

If integration is in process when Verb 47 is initiated, the Verb 47 process is delayed until integration is completed. If integration is not in process, the LM state vector (position, velocity, time) is transferred to the CSM state vector registers.

10.2.10 Verb 48

Extended Verb 48 calls R03, CSM DAP Data Load Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. If Verb 48 is selected while the TVC DAP is on, the OPR ERR DSKY light will be illuminated. Refer to paragraph 9.2.1 and Figure 9.2.1-1 for a description of R03.

10.2.11 Verb 49

Extended Verb 49 calls R62, the Crew-Defined Maneuver Routine. Unless a fresh start situation exists (blank major mode) or P00 is operating, the process will not be initiated and the OPR ERR DSKY light will be illuminated. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb

interlock is set by this process. Refer to paragraph 2.2.1.4.1 and Figure 2.2.1-2 for a description of R62.

10.2.12 Verb 52

Extended Verb 52 is used to set the offset landing site designator index for P22. Selection of Verb 52 at any time except during P22 will result in the illumination of the OPR ERR DSKY light. Refer to paragraph 4.2.3 for details.

10.2.13 Verb 54

Extended Verb 54 calls R23, the Rendezvous Backup Sighting Mark Routine. The process enables sighting marks in conjunction with options 0 or 4 of the Universal Tracking Program (P20) using the backup device, COAS. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Selection of Verb 54 at any time except when tracking is enabled during options 0 or 4 of P20 will result in a PROG alarm (code 00406). Refer to paragraph 4.2.1.2.2, Table 4.2.1-III, and Figure 4.2.1-11 for details.

10.2.14 Verb 55

Extended Verb 55 enables the crew to increment or decrement the CMC time (GET). If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. For a description of the procedure, refer to paragraph 10.3.11. The process is the same for the CMC and the LGC.

10.2.15 Verb 56

Extended Verb 56 terminates P20, the Universal Tracking Program. It will also terminate MINKEY. It will not terminate other programs running in conjunction with P20. If P20 is running, a software restart will occur. If P20 is the only program running, R00 will be selected. Verb 56 has no effect if P20 is not enabled. Refer also to paragraph 4.2.1 and Table 4.2.1-III.

10.2.16 Verb 57

Extended Verb 57 displays the status of the tracking (SXT only, VHF only, or both), and allows the change of that status by DSKY entry. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer also to paragraph 4.2.1.2, paragraph 4.2.1.2.6.4, and Table 4.2.1-III.

Procedure

1. Key VERB 57 ENTR
2. Observe flashing display of option code for full or partial tracking:

   FL VERB 04 NOUN 12

   R1 00004
   R2 0000x
   R3 blank

   NOTE.—R2 is the current status of FULTKFLG: Option code values are:

VALUE	MEANING
00000	FULL TRACKING (SXT AND VHF)
00001	PARTIAL TRACKING (SXT only or VHF only)

3. To change status, key VERB 22 ENTR and load desired option code.
4. Key PRO.
5. Exit Verb 57.

   NOTE.—If step 3 is interrupted by a priority display or a restart, step 3 (and if necessary, steps 1 and 2) should be repeated to ensure that the desired flag setting is obtained.

10.2.17 Verb 58

Extended Verb 58 resets the STIKFLAG and sets V50N18FL to enable an automatic maneuver (R60) in options 0, 1, 4 and 5 of P20, Universal Tracking Program. For further description of the process refer to paragraph 4.2.1.2.2.2 and Table 4.2.1-III.

10.2.18 Verb 60

Extended Verb 60 is used to set the registers associated with Noun 17 equal to the registers associated with Noun 20. Noun 17 registers are those which display the astronaut total attitude while Noun 20 provides the present attitude. Refer to Table 4.2.1-III. See also Verb 63 (paragraph 10.2.21).

10.2.19 Verb 61

Extended Verb 61 initiates the display of the Mode 1 (DAP attitude) error on the FDAI error needles. Refer to Table 4.2.1-III for details.

10.2.20 Verb 62

Extended Verb 62 initiates the display of the Mode 2 (total attitude) error (the difference between Noun 22 and Noun 20) on the FDAI error needles. Refer to Table 4.2.1-III for details.

10.2.21 VERB 63

Extended Verb 63 initiates the display of the Mode 3 (total astronaut attitude) error (the difference between Noun 17 and Noun 20) on the FDAI error needles. Refer to Table 4.2.1-III for details.

10.2.22 Verb 64

Extended Verb 64 initiates the S-band Antenna Routine, R05. If the extended verb interlock has been set by a currently operating extended verb, the process will not

be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 9.2.2 for a description of R05.

10.2.23 Verb 65

Extended Verb 65 is used during P02 to select P03. Selection of Verb 65 at any time except during P02 will result in the illumination of the OPR ERR DSKY light. Refer to paragraph 2.2.4 for a description of P03.

10.2.24 Verb 66

Extended Verb 66 transfers the CSM state vector information to the LM state vector registers. During AVERAGEG, Verb 66 should not be selected, since the pre-burn value of the CSM state vector rather than the current value will be transferred and the CSM state vector may be destroyed. See also Verb 47 (paragraph 10.2.9).

If integration is in process when Verb 66 is initiated, the Verb 66 process is delayed until integration is completed. If integration is not in process, the CSM state vector (position, velocity, time) is transferred to the LM state vector registers.

10.2.25 Verb 67

Extended Verb 67 displays the W-matrix RSS error and allows a re-initialization of the W-matrix if desired by the crew. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer also to paragraph 4.2.1.2.2.2 and Table 4.2.1-III.

Procedure

1. Key VERB 67 ENTR
2. Observe flashing display of W-matrix RSS position and velocity errors:

FL VERB 06 NOUN 99

R1	xxxxx. ft	RSS Position error
R2	xxxx.x fps	RSS Velocity error
R3	xxxxx.	Option Code

<u>Note.</u>—The option code defines which process will be initialized if the Noun 99 display is changed. Option code values are:

Value	Meaning
00000	No initialization
00001	Rendezvous
00002	Orbital
00003	Cislunar

3. To allow initialization of the W-matrix, key VERB 25 ENTR and load new data, making sure that R3 of Noun 99 contains the proper option code for the process for which the initialization is done.
4. Key PRO.
5. Exit Verb 67.

<u>NOTE.</u>—Selection of option 1 will not result in W-matrix initialization until Verb 93 is performed (paragraph 10.2.45.)

10.2.26 <u>Verb 69</u>

Extended Verb 69 is used to cause a crew-initiated computer restart. The CMC Verb 69 is identical in procedure and operation to the LGC Verb 69. Refer to paragraph 10.3.25.

10.2.27 <u>Verb 70</u>

Extended Verb 70 is used to initiate P27 to update liftoff time. Refer to paragraph 4.2.5 and Table 4.2.5-II for details.

10.2.28 Verb 71

Extended Verb 71 is used to initiate P27 for a block update. Refer to paragraph 4.2.5 and Table 4.2.5-II for details.

10.2.29 Verb 72

Extended Verb 72 is used to initiate P27 for a scatter update. Refer to paragraph 4.2.5 and Table 4.2.5-II for details.

10.2.30 Verb 73

Extended Verb 73 is used to initiate P27 to update the CMC clock. Refer to paragraph 4.2.5 and Table 4.2.5-II for details.

10.2.31 Verb 74

Extended Verb 74 is used to terminate the existing downlink list and to begin downlink of all of erasable memory. Two complete memory dumps are performed (taking 41.6 seconds at high bit rate) and then the current downlink list is restored.

10.2.32 Verb 75

Extended Verb 75 is a back-up procedure for setting the liftoff discrete in order to initiate P11, the Earth Orbit Insertion Monitor Program. This process is intended for the prelaunch portion of the mission, specifically during P02, the Gyro Compassing Program. Refer to paragraph 2.2.3, paragraph 3.2.1.2, and Table 3.2.1-II for details.

10.2.33 Verb 78

Extended Verb 78 is used in P02 to enable the crew to change the launch azimuth. Selection of Verb 78 at any time except during P02 will result in the illumination of the OPR ERR DSKY light. Refer to paragraph 2.2.3 for details.

10.2.34 Verb 80

Extended Verb 80 enables the LM state vector to be updated during P20 options 0 and 4. Selection of P20 automatically enables this, so Verb 80 is not required unless Verb 81 has been performed since the start of P20. Refer to Table 4.2.1-III.

10.2.35 Verb 81

Extended Verb 81 enables the CSM state vector to be updated during P20. Selection of P20 automatically enables the LM state vector to be updated. Refer to Table 4.2.1-III.

10.2.36 Verb 82

Extended Verb 82 is used to call R30, the Orbital Parameters Display Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 9.2.3 and Figure 9.2.3-1 for a description of R30. See also paragraph 3.2.1.4, Table 3.2.1-II, Table 4.2.1-III, Table 6.2.1-II, Table 6.2.2-II, and Table 6.2.3-II.

10.2.37 Verb 83

Extended Verb 83 is used to call R31, the Rendezvous Parameter Display No. 1 Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 9.2.4 and Figure 9.2.4-2 for a description of R31. Refer also to paragraph 4.2.1.2.2.2, Sequence V, Final Phase, Table 4.2.1-III, Table 6.2.1-II, Table 6.2.2-II, and Table 6.2.3-II.

10.2.38 Verb 85

Extended Verb 85 is used to call R34, the Rendezvous Parameter Display No. 2 Routine. If the extended verb interlock has been set by a currently operating extended

verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 9.2.5 and Figure 9.2.5-2 for a description of R34. Refer also to Table 4.2.1-III, and Table 6.2.3-II.

10.2.39 Verb 86

Extended Verb 86 enables the crew to reject a mark taken while using R23, the Rendezvous Backup Sighting Mark Routine, or R21, the Rendezvous Tracking Sighting Mark Routine. The process can be used in options 0 or 4 of P20, the Universal Tracking Program. Refer to Table 4.2.1-III.

10.2.40 Verb 87

Extended Verb 87 sets the VHF range flag (VHFRFLAG), allowing R22 to accept VHF range data. VHFRFLAG is automatically set during MINKEY; it must be manually set following each VERB 37 ENTR xx ENTR otherwise. Refer to Table 4.2.1-III.

10.2.41 Verb 88

Extended Verb 88 resets the VHF range flag (VHFRFLAG), inhibiting VHF range data acceptance by R22. VHFRFLAG is automatically set during MINKEY; it will be automatically reset by each VERB 37 ENTR xx ENTR otherwise. Refer to Table 4.2.1-III.

10.2.42 Verb 89

Extended Verb 89 is used to call R63, the Rendezvous Final Attitude Routine. Unless a fresh start situation exists (blank major mode) or P00 is operating, the process will not be initiated and the OPR ERR DSKY light will be illuminated. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. For a description of R63, refer to paragraph 2.2.1.4.2 and Figure 2.2.1-4. See also Table 4.2.1-III.

10.2.43 Verb 90

Extended Verb 90 is used to call R36, the Rendezvous Out-of-Plane Display Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. For a description of R36, refer to paragraph 9.2.6, and Figure 9.2.6-1. See also Table 4.2.1-III.

10.2.44 Verb 91

Extended Verb 91 displays the banksum for each bank on the DSKY. Unless a fresh start situation exists (blank major mode) or P00 is operating, the process will not be initiated and the OPR ERR DSKY light will be illuminated. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. For a description of Verb 91 use, refer to paragraph 2.2.1.4.3.3 and Figure 2.2.1-7.

10.2.45 Verb 93

Extended Verb 93 allows re-initialization of the W-matrix. Refer to Table 4.2.1-III and paragraph 4.2.1.2.2.2.

10.2.46 Verb 94

Extended Verb 94 allows the astronaut to recycle during P23, the Cislunar Midcourse Navigation Program. Selection of Verb 94 at any time except when R52 is running during P23 will result in the illumination of the OPR ERR DSKY light. Refer to paragraph 4.2.4.2 (step 16).

10.2.47 Verb 96

Extended Verb 96 terminates current activity and initiates the CMC Idling Program P00. Refer to paragraphs 2.2.1.1 and 10.3.47 for details.

SUBSECTION 10.3

LGC EXTENDED VERBS

BLANK

10.3.1 Verb 40 Noun 20

Extended Verb 40 (Noun 20) zeroes the Inertial Measurement Unit (IMU) CDUs. The process can be selected if the Inertial Subsystem (ISS) is not in the coarse align mode and gimbal lock. Refer to paragraph 7.3.2.6, Table 7.3.2-II, and Figure 7.3.2-15 for details.

10.3.2 Verb 40 Noun 72

Extended Verb 40 (Noun 72) zeroes the Rendezvous Radar (RR) CDUs. Verb 40 Noun 72 may not be selected while the TRACKFLG is set, during R77, or in P63, P64, or P66 when R12 is operating; the OPR ERR DSKY light will be illuminated in these cases. Refer to Table 4.3.1-II.

10.3.3 Verb 41 Noun 20

Extended Verb 41 (Noun 20) coarse aligns the Inertial Measurement Unit (IMU). If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 7.3.2.6, Table 7.3.2-II and Figure 7.3.2-13 for details.

10.3.4 Verb 41 Noun 72

Extended Verb 41 (Noun 72) coarse aligns the Rendezvous Radar (RR) CDUs. Verb 41 Noun 72 may not be selected while the TRACKFLG is set, during R77, or in P63, P64, or P66 when R12 is operating; the OPR ERR DSKY light will be illuminated in these cases. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to Table 4.3.3-IV.

Procedures

1. Key VERB 41 NOUN 72 ENTR
2. Observe flashing display of request to load desired RR angles:

FL VERB 21 NOUN 73

R1	±xxx.xx deg	Desired RR trunnion angle
R2	±xxx.xx deg	Desired RR shaft angle
R3	blank	

NOTE.—R1 and R2 will initially be blank

3. Key ±xxxxx ENTR ±xxxxx ENTR to load desired trunnion and shaft angles.
4. Observe flashing display of designate option request:

FL VERB 04 NOUN 12

R1	00006	Designate option request
R2	0000x	Option code
R3	blank	

NOTE.—The option code defines what RR process will occur after the RR drives to the desired angles. Option code values are:

Value	Meaning
00001	Lock-on
00002	Continuous designate

5. The process will initially display option code 00002. If the lock-on option is desired, key VERB 22 ENTR 1 ENTR. When satisfied with the option code, key PRO. The RR now drives to the specified angles.

NOTE.—If the angles are not within the legal RR mode limits (see Figure 4.3.1-3) the RR will not drive, the PROG light will be illuminated on the DSKY (alarm code 00502) and Verb 41 Noun 72 will exit.

NOTE.—The RR mode control switch on the RADAR panel must be in the LGC position when Verb 41 Noun 72 is selected; if it is not, the RR antenna will not be driven to the desired angles.

LOCK-ON OPTION

If the lock-on option was selected, the RR will lock-on and the data good discrete will be received. Verb 41 Noun 72 will then exit.

> NOTE.—If the data good discrete does not appear within approximately 30 seconds, or if a RR CDU fail occurs, the PROG light will be illuminated on the DSKY (alarm code 00503) and Verb 41 Noun 72 will exit.

CONTINUOUS DESIGNATE OPTION

If the continuous designate option was selected, the process continues driving the RR to the desired angles until the crew selects Verb 44 (paragraph 10.3.7). To monitor driving, the crew may key VERB 16 NOUN 72 ENTR.

10.3.5 Verb 42

Extended Verb 42 fine aligns the Inertial Measurement Unit (IMU) by torquing the gyros. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 7.3.2.6, Table 7.3.2-II, and Figure 7.3.2-14 for details.

10.3.6 Verb 43

Extended Verb 43 allows the crew to specify new angle increments for the FDAI error needles. Unless a fresh start situation exists (blank major mode) or P00 is operating, the process will not be initiated and the OPR ERR DSKY light will be illuminated. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. If the IMU is not in the fine align mode or if the DAP is on when Verb 43 is selected, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The LGC Verb 43 procedure and function is the same as that of the CMC Verb 43 except that the angles specified are used to increment the needles. Refer to paragraph 2.2.1.4.3.2 and Figure 2.2.1-6.

10.3.7 Verb 44

Extended Verb 44 terminates the Rendezvous Radar (RR) continuous designate option. Refer to Tables 4.3.1-II and 4.3.3-IV.

10.3.8 Verb 47

Extended Verb 47 is used to initiate execution of R47, the AGS Initialization Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 3.3.2.2.4 and Figure 3.3.2-5 for a description of R47.

10.3.9 Verb 48

Extended Verb 48 is used to initiate execution of R03, the Digital Autopilot (DAP) Data Load Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. For a description of R03, see paragraph 9.3.1.

10.3.10 Verb 49

Extended Verb 49 is used to initiate execution of R62, the Crew-Defined Maneuver Routine. Unless a fresh start situation exists (blank major mode) or P00 is operating, the process will not be initiated and the OPR ERR DSKY light will be illuminated. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. The LGC Verb 49 procedure and function is the same as that of the CMC Verb 49 except that the automatic maneuver is not terminated by deflection of the ACA. For a description of R62, see paragraph 2.2.1.4.1, and Figure 2.2.1-2.

10.3.11 Verb 55

Extended Verb 55 is used to initiate the process of changing the LGC clock time (GET) using decimal increments (or decrements) loaded by the astronaut. If the

extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process.

Procedures

1. Key VERB 55 ENTR.
2. Observe DSKY display of request to load clock increment (decrement)

   FL VERB 21 NOUN 24

R1	±ooxxx.	Hours
R2	±oooxx.	Minutes
R3	±oxx.xx	Seconds

   NOTE.—R1, R2, and R3 will initially be blank.

   - Load desired time increment (decrement). Go to Step 3.
   - Terminate via VERB 34 ENTR or VERB 33 ENTR if it is not desired to increment the LGC clock time.

3. Exit Verb 55

   NOTE.—If desired time increment loaded, LGC clock time (GET) can be monitored via:

   VERB 16 NOUN 65 ENTR

R1	±ooxxx.	Hours
R2	±oooxx.	Minutes
R3	±oxx.xx	Seconds

10.3.12 Verb 56

Extended Verb 56 calls R56, the Terminate Tracking Routine and terminates P20, the LGC Rendezvous Navigation Program, P22, the Lunar Surface Navigation Program, and P25, the Preferred Tracking Attitude Program. Verb 56 will have no effect unless P22 is running or P20 or P25 is enabled. Refer to paragraph 4.3.1.4.9, Figure 4.3.1-13, Figure 4.3.4-4, and Table 4.3.3-IV.

10.3.13 Verb 57

Extended Verb 57 permits landing radar data to be incorporated into the LM state vector by the Descent State Vector Update Routine (R12) during the LM descent portion of the lunar landing. The process is effective only in R12. The process is normally selected in P63, the Braking Phase Program at about 40,000 feet, when R1 of VERB 06 NOUN 63 (DELTAH) ceases to equal +99999, and reaches a value within mission limits. The process causes the LR Permit flag to be set.

When LR updates are being allowed in P63 a flashing DSKY display, VERB 06 NOUN 63, is replaced with a static display of the same verb–noun. In P64 or P66, Noun 63 can be monitored via Verb 16. For information on inhibiting LR update data incorporation, see Verb 58, paragraph 10.3.14. Refer also to paragraph 8.3.2.2.

10.3.14 Verb 58

Extended Verb 58 inhibits incorporation of landing radar update data into the LM state vector by the Descent State Vector Update Routine (R12) during the LM descent portion of the lunar landing. The process is effective only in R12, and is selected with the assumption that extended Verb 57 (see paragraph 10.3.13) has been previously selected and LR data incorporation is such that the crew desires the termination of the data incorporation portion of R12 because R1 of NOUN 63 (DELTAH) is diverging, i.e., is too large for this portion of the mission phase, or because LR data incorporation is otherwise unsatisfactory. The process causes the LR Permit flag to be reset.

When the LR Permit flag is reset during P63, the new DSKY display observed by the astronaut is the flashing VERB 06 NOUN 63, rather than the static VERB 06 NOUN 63 display caused by performing extended Verb 57. During P64 or P66, NOUN 63 can be monitored by keying VERB 16 NOUN 63 ENTR. For details on allowing the incorporation of LR update data, see Verb 57, paragraph 10.3.13.

10.3.15 Verb 59

Extended Verb 59 is used to command the LR from position 1 to position 2 for the approach of the LM to the lunar landing site. If AVERAGEG is running, the process is restricted to P63, P64 or P66; the OPR ERR DSKY light will be illuminated during AVERAGEG otherwise. The process is not nominally selected during the

lunar landing. When LR antenna positioning is in process during lunar landing the LR data fail lights on the DSKY panel (ALT and VEL) are illuminated and the DSKY display of VERB 06 NOUN 63, R1 (DELTAH) will become static until the antenna positioning routine has finished and data is again accepted by the LR Data Read Routine. During P64 or P66, NOUN 63 can be monitored by keying VERB 16 NOUN 63 ENTR. Should the LR or RR be in use by some other program the crew can either discontinue efforts to initiate the LR Positioning Routine, or terminate the other program or routine that prevents selection of Verb 59.

During lunar landing, when ALT and VEL lights extinguish and R1 of VERB 06 NOUN 63 begins to change value, the positioning routine has ended. The LR antenna should now be in position 2 for the approach to the lunar landing site; and the LR Data Read Routine should be obtaining LR data for use in R12.

Possible Alarm

During the repositioning, the DSKY panel light PROG may illuminate signaling a program alarm. If so, the alarm code can be observed by keying VERB 05 NOUN 09 ENTR. Alarm code 00523, appearing in R1, R2, or R3 indicates that Verb 59 was not successful in that the LR antenna did not achieve position 2.* The crew can then depress KEY REL and RSET to extinguish the program alarm DSKY panel light PROG and return to any display that was visible before Verb 05 Noun 09 was initiated.

10.3.16 Verb 60

Extended Verb 60 initiates the display of PGNCS-derived vehicle attitude rates on the FDAI error needles. See Tables 3.3.1-I, 3.3.2-I, 3.3.3-I, and 4.3.1-II for details.

10.3.17 Verb 61

Extended Verb 61 initiates the display of the Mode 1 (DAP attitude) error on the FDAI error needles. Refer to Tables 3.3.1-I, 3.3.2-I, 3.3.3-I, and 4.3.1-II.

*During lunar landing, this alarm will not occur.

10.3.18 Verb 62

Extended Verb 62 initiates the display of the Mode 2 (total attitude) error on the FDAI error needles. This display is also initiated by R60. Refer to Tables 3.3.1-I, 3.3.2-I, 3.3.3-I, and 4.3.1-II.

10.3.19 Verb 63

Extended Verb 63 is used to initiate R04, the RR/LR Self-Test Routine. Verb 63 may not be selected when the TRACKFLG is set, during R77, or in P63, P64, or P66 when R12 is operating; the OPR ERR DSKY light will be illuminated in these cases. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 4.3.1.4.2, Figure 4.3.1-6, and Table 4.3.1-II for details.

10.3.20 Verb 64

Extended Verb 64 is used to initiate R05, the S-band Antenna Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 9.3.6 for a description of R05.

10.3.21 Verb 65

Extended Verb 65 causes the U and V RCS jets to be disabled during DPS powered flight. The crew can select Verb 65 at any time. The process of disabling the U and V jets involves setting the SNUFFER flag so that the digital autopilot (DAP) is informed of the desired action. Refer to Table 3.3.2-I for details.

10.3.22 Verb 66

Extended Verb 66 is used to transfer the LM state vector information to the CSM state vector registers. Verb 66 is callable any time except when the LM is on the lunar surface; in this case, the OPR ERR DSKY light will be illuminated. During AVERAGEG, the pre-burn value of the LM state vector rather than the current value will be transferred.

If integration is in process when Verb 66 is initiated, the Verb 66 process is delayed until integration is completed. If integration is not in process, the LM state vector (position, velocity, time) is transferred to the CSM state vector registers.

10.3.23 Verb 67

Extended Verb 67 displays the W-matrix RSS error and allows a re-initialization of the W-matrix if desired by the crew. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to Table 4.3.1-II and Table 4.3.3-IV.

Procedure

1. Key VERB 67 ENTR
2. Observe flashing display of W-matrix RSS position, velocity, and bias errors.

   FL VERB 06 NOUN 99

R1	xxxxx. ft.	RSS Position error
R2	xxxx.x fps	RSS Velocity error
R3	xxxxx. mr.	RSS Bias error

3. To initialize the W-matrix, key VERB 25 ENTR and load new data.
4. Key PRO
5. Exit Verb 67.

10.3.24 Verb 68

Extended Verb 68 permits the astronaut to command the LGC to bypass the lunar terrain model when computing the data to be used in updating the LM state vector during the Descent State Vector Update Routine (R12). The crew may wish to inhibit the incorporation of the lunar terrain model because of any adverse effects due to terrain mismatch or because of extremely large altitude errors between the modeled terrain and the actual terrain.

10.3.25 Verb 69

Extended Verb 69 is used to cause a crew-initiated computer restart. Selection of Verb 69 causes an automatic hardware restart. All current jobs and tasks are terminated; then, all restartable jobs and tasks are restarted. Verb 69 can be selected at any time.

Procedure

1. Key VERB 69 ENTR
2. Monitor DSKY and observe RESTART light illuminated on DSKY panel. DSKY should re-establish the last restartable display of the current major mode.
3. Key RSET to extinguish RESTART light.
4. Exit Verb 69.

Possible Alarm

If the DSKY panel light PROG is illuminated, key VERB 05 NOUN 09 ENTR. If R1, R2, or R3 of Noun 09 is 01107, the crew performs the fresh start procedures and exits Verb 69. If R1, R2, or R3, of Noun 09 is not 01107, the crew exits Verb 69 normally.

10.3.26 Verb 70

Extended Verb 70 is used to initiate P27 to update liftoff time. Refer to paragraph 4.3.5 for details.

10.3.27 Verb 71

Extended Verb 71 is used to initiate P27 for a block update. Refer to paragraph 4.3.5 for details.

10.3.28 Verb 72

Extended Verb 72 is used to initiate P27 for a scatter update. Refer to paragraph 4.3.5 for details.

10.3.29 Verb 73

Extended Verb 73 is used to initiate P27 to update the LGC clock. Refer to paragraph 4.3.5 for details.

10.3.30 Verb 74

Extended Verb 74 is used to terminate the existing downlink list and to begin downlink of all of erasable memory. Two complete memory dumps are performed (taking 41.6 seconds at high bit rate) and then the current downlink list is restored.

10.3.31 Verb 75

Extended Verb 75 enables the DAP U, V jets during DPS burns. The procedure is exactly opposite to that described for Verb 65 in paragraph 10.3.21, in that Verb 75 resets the SNUFFER flag. Refer to Table 3.3.2-I for details.

10.3.32 Verb 76

Extended Verb 76 enables the minimum impulse command mode of the DAP by setting PULSES flag. To obtain the minimum impulse mode, the GUID CONT switch must be set to PGNS and the PGNS MODE CONTROL switch set to ATT HOLD. The minimum impulse mode will remain enabled until cancelled by the rate command mode enabled by Verb 77 (paragraph 10.3.33) or by the powered flight programs P12, P40, P41, P42, P63, P70, P71. Refer to Table 3.3.1-I, Table 3.3.2-I, and Table 3.3.3-I for details.

10.3.33 Verb 77

Extended Verb 77 is used to enable the rate command mode of the DAP. It will also initialize the desired ICDU angles to the actual ICDU angles. Verb 77 can be selected by the crew at any time. To obtain the rate command mode, the GUID

CONT switch must be set to PGNS and the PGNS MODE CONTROL switch set to ATT HOLD. The rate command mode will remain enabled until cancelled by either P68 or by minimum impulse mode selection (Verb 76, paragraph 10.3.32). The rate command mode is enabled by resetting PULSES flag. Refer to Table 3.3.1-I, Table 3.3.2-I, and Table 3.3.3-I for details.

10.3.34 Verb 78

Extended Verb 78 is used to call R77, the LR Spurious Test Routine. Verb 78 may not be selected when the TRACKFLG is set, during R04, or in P63, P64, or P66 when R12 is operating; the OPR ERR DSKY light will be illuminated in these cases. Refer to paragraph 9.3.5 for details.

10.3.35 Verb 79

Extended Verb 79 is used to terminate R77, the LR Spurious Test Routine. Refer to paragraph 9.3.5 for details.

10.3.36 Verb 80

Extended Verb 80 enables the LM state vector to be updated by the Rendezvous Radar during P20 or P22. Selection of P22 automatically enables the CSM state vector to be updated, and selection of P20 automatically enables the LM state vector to be updated (unless Verb 95 has been executed). Refer to paragraph 4.3.1, and Table 4.3.1-II for details.

10.3.37 Verb 81

Extended Verb 81 enables the CSM state vector to be updated by the Rendezvous Radar in P20 or P22. Selection of P22 automatically enables the CSM state vector to be updated, and selection of P20 automatically enables the LM state vector to be updated (unless Verb 95 has been executed). Refer to paragraph 10.3.36, paragraph 4.3.1, and Table 4.3.1-II for details.

10.3.38 Verb 82

Extended Verb 82 is used to call R30, the Orbit Parameter Display Routine. If the extended verb interlock has been set by a currently operating extended verb,

the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. For a description of R30, refer to paragraph 9.3.2, and Figure 9.3.2-1. See also Table 3.3.1-I, Table 3.3.2-I, Table 3.3.3-I, Table 6.3.1-II, Table 6.3.2-II, Table 6.3.3-II, and Table 6.3.4-II.

10.3.39 Verb 83

Extended Verb 83 is used to call R31, the Rendezvous Parameter Display Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. The LGC Verb 83 procedure is the same as that of the CMC Verb 83 except that the LM +Z-axis is used instead of the CSM +X-axis. Refer to paragraph 9.2.4 and Figure 9.2.4-2 for a description of R31. See also Table 4.3.3-IV, Table 6.3.1-II, Table 6.3.2-II, Table 6.3.3-II, and Table 6.3.4-II.

10.3.40 Verb 85

Extended Verb 85 initiates the display of the Rendezvous Radar (RR) line of sight (LOS) azimuth and elevation. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to Table 3.3.1-I, Table 4.3.1-II, and Table 4.3.3-IV.

10.3.41 Verb 89

Extended Verb 89 is used to call R63, the Rendezvous Final Attitude Routine. Unless a fresh start situation exists (blank major mode) or P00 is operating, the process will not be initiated and the OPR ERR DSKY light will be illuminated. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Refer to paragraph 9.3.4 and Figure 9.3.4-1 for a description of R63.

10.3.42 Verb 90

Extended Verb 90 is used to call R36, the Rendezvous Out-of-plane Display Routine. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. Verb 90 may not be selected while AVERAGEG is running; if it is attempted, the OPR ERR DSKY light will be illuminated. Refer to paragraph 9.3.3 and Figure 9.3.3-1 for a description of R36.

10.3.43 Verb 91

Extended Verb 91 is used to display the sum of each bank. Unless a fresh start situation exists (blank major mode) or P00 is operating, the process will not be initiated and the OPR ERR DSKY light will be illuminated. If the extended verb interlock has been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process. The LGC Verb 91 procedure is the same as that for the CMC Verb 91. Refer to paragraph 2.2.1.4.3.3 and Figure 2.2.1-7.

10.3.44 Verb 92

Extended Verb 92 is used to operate the IMU Performance Test Program, P07. P07 is intended for ground use only during the prelaunch phase, and is described in Section 1 of R567. Verb 92 may be selected only if NODOP07 is reset; otherwise P07 will not be initiated and the OPR ERR DSKY light will be illuminated. NODOP07 is set by keying VERB 37 ENTR xx ENTR. If the extended verb interlock is been set by a currently operating extended verb, the process will not be initiated and the OPR ERR DSKY light will be illuminated. The extended verb interlock is set by this process.

10.3.45 Verb 93

Extended Verb 93 allows the W-matrix to be re-initialized. Refer to Table 4.3.1-II.

10.3.46 Verb 95

Extended Verb 95 inhibits the update of either state vector (LM or CSM) by P20, the Rendezvous Navigation Program and P22, the Lunar-surface Navigation Program.

Refer to Table 4.3.1-II and 4.3.3-IV. See also Verb 80 (paragraph 10.3.36) and Verb 81 (paragraph 10.3.37).

10.3.47 Verb 96

Extended Verb 96 provides a means of suspending state vector integration if it is in progress and activating the LGC Idling Program P00. The current program is terminated, P00 is initiated, and P00 state vector integration is bypassed until a new program selection is made. The process does not maintain state vector synchronization. If the coasting integration routine is in operation, it is terminated at the current time step.

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